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HIGH-VELOCITY IMPACT TESTS INVOLVING THIN SPHERICAL SHELLS OF
TANTALUM AND 304 STAINLESS STEEL

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CONTENTS

Abstract	1
Introduction	1
Overview	2
Results	10
Comments	11
Acknowledgments	13
References	15
Appendix A — Shell Deformation Data	16
Appendix B — Dot Distortion Data	20
Appendix C — Background Information	47
Preparation of Test Specimens	47
Instrumentation	47
Sabot Design	52
Experimental Procedure	53

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HIGH-VELOCITY IMPACT TESTS INVOLVING THIN SPHERICAL SHELLS OF TANTALUM AND 304 STAINLESS STEEL

ABSTRACT

This experimental program generated data to improve computer-code modeling of impact phenomena. The improved computation technique will be used to design a fissile-material container able to withstand a 335 m/s impact. The program involved flyer-plate-impact tests using thin shells of annealed 304 stainless steel and annealed tantalum at impact velocities of 28-180 m/s. No active instrumentation was used in this study; instead, all data were derived from measurements of test specimens. Pre- and post-test measurement of interior and exterior dot patterns etched on the shells provided surface-strain information. Radiographs of the deformed shells provided shell-contour data that we plotted vs impact velocity. Curves were fit to these data. We found that normalized crush height varies almost linearly with impact velocity for both materials, that normalized radius of contact varies directly with impact velocity for both materials but appears independent of shell thickness for tantalum, and that normalized interior-fold radius varies inversely with impact velocity and directly with shell thickness for stainless steel, but no clear relationship appears for tantalum.

INTRODUCTION

In the past 10-15 years, a few military aircraft bearing nuclear weapons have crashed. The impact broke up the weapons, which contaminated the crash site with radioactive material. These accidents stimulated an interest in crash-resistant weapons. Lawrence Livermore Laboratory has begun several programs to attack this problem in various ways. This report summarizes one small experimental program to determine the impact resistance of relatively thin spherical shells. Data from impact tests of these shells will be developed into an analytical tool for designing a thin-shell container for fissile material able to withstand a 335 m/s impact without leaking.

The experimental program tested shell material, wall thickness, and impact velocity. Shells were fabricated from annealed tantalum and annealed

304 stainless steel. The inner radius of all shells was 38.1 mm, but the outer radius varied to yield radius-to-thickness (R/t) ratios of 25, 38, and 79. Impact velocities varied from 28 to 180 m/s.

A dot pattern etched on each shell was carefully measured before the test. During the test, the shell deformed by impact with a flyer plate mounted in a sabot. To minimize any additional deformation, the sabot and shell were decelerated in a rag-filled container. Shell mass, flyer-sabot mass, and impact velocity were recorded during the test. Afterward, the shell was first checked for tightness by a helium leak test, then radiographed. The outline of the deformed shell was traced from the radiograph and overlaid with outlines of other shells of the same material and R/t ratio. Figures 1 and 2 present these overlays. I measured the radiograph for crush height, radius of impact surface, depth of impact-surface depression, and interior shell-fold radius at the impact-surface edge. Appendix A shows these data. I plotted dimensionless parameters vs impact velocity and fit curves to the plots. Figures 3-7 reveal plots and fitted curves. After radiography, the shell was cut apart at the weld seam and the interior and exterior dot pattern measured. Appendix B presents the dot distortion data thus acquired, and Appendix C describes shell fabrication and etching, sabot design, and experimental procedure.

OVERVIEW

We compared tantalum shells and stainless steel 304 shells. Tantalum has the ductility and modulus of steel, is fairly well characterized, and has a high melt temperature. Stainless steel 304 is well characterized and provides a standard of comparison. In addition, published literature provides experimental impact data for large shells of stainless steel 304.¹ We include stainless steel 304 in the present study to help scale results from small-diameter shells (76 mm) to the larger-diameter shells (640 mm) used in the cited report.

The R/t ratios selected for study cover the range of interest, 25-80. A shell with an R/t ratio of 80 fails by buckling. As the shell buckles, folds form. The folds flatten at high-impact velocities (>120 m/s), causing localized stretching of the metal and subsequent tearing. Thinner shells (those with R/t ratios >80) fail in a similar manner and are increasingly sensitive to handling. Therefore, an R/t ratio of 80 is the upper range of interest.

Fig. 1. Superimposed tracings of annealed tantalum shell contours after impact at specified velocities. The inner radius (R) of each shell is 76 mm. Wall thicknesses (t) vary as indicated by R/t ratios.

Fig. 2. Superimposed tracings of annealed 304 stainless steel shell contours after impact at specified velocities. The inner radius (R) of each shell is 76 mm. Wall thicknesses (t) vary as indicated by R/t ratios.

Fig. 3. Ratio of normalized crush height for annealed tantalum shells vs impact velocity. T is normalized to external diameter of shell before impact ($2R$). See Fig. A. 1 for key to symbols.

Fig. 4. Ratio of normalized crush height for annealed 304 stainless steel shells vs impact velocity. T is normalized to external diameter of shell before impact ($2R$). See Fig. A. 1 for key to symbols.

Fig. 5. Ratio of normalized radius of contact for annealed tantalum vs impact velocity. Radius of contact (ρ) is radius of shell impact surface in impact plane and is normalized to external radius of shell before impact (R_0). See Fig. A. 1 for key to symbols.

Fig. 6. Ratio of normalized radius of contact for annealed 304 stainless steel vs impact velocity. Radius of contact (ρ) is radius of shell impact surface in impact plane and is normalized to external radius of shell before impact (R_0). See Fig. A. 1 for key to symbols.

Fig. 7. Ratio of normalized interior-fold radius for annealed 304 stainless steel vs impact velocity. Interior-fold radius (r) is internal radius of fold at edge of impact surface and is normalized to internal radius of shell before impact (R_i). See Fig. A. 1 for key to symbols.

On the other hand, a shell with an R/t ratio of 25 fails by being stressed above some shear-stress limit. As the shell deforms, a shear-stress gradient is established through the wall thickness. At sufficiently high stress levels, the shell tears from the inside out. Thicker shells (those with R/t ratios <25) would be susceptible to this type of failure. In addition, each shell must be retrieved after test in order to gather data. A thick shell is more massive than a thin one and requires a correspondingly more massive sabot. The momentum of these more massive pieces can exceed the energy-absorbing ability of the recovery system. For these reasons, a shell with R/t of 25 represents the lower range of interest.

We selected impact velocities for testing at each R/t value according to the following three factors: (1) records indicating the crash speeds of military aircraft (up to 335 m/s), (2) impressions of shell impact survivability gained from published reports,^{1,2} and (3) experience gained from preliminary impact tests using thin (R/t = 70) shells. The following R/t ratios and impact velocities were selected as test values:

R/t	Impact velocities,		m/s		
25	84	118	165		
38	60	83	118	165	
79	30	42	60	82	115

For the lowest impact velocity of each R/t group, we arbitrarily chose one that a shell can withstand with mild deformation. Each velocity step beyond corresponds to doubling the kinetic energy of the sabot at impact.

RESULTS

These shell-impact tests yielded four significant conclusions.

First, radiographs of post-test specimens provided accurate contours of annealed tantalum and annealed 304 stainless steel shells of various thicknesses and at various impact velocities. Superimposed tracings of these shell contours (Figs. 1 and 2) clearly show the effects of increased impact velocities

on shells of each material and each thickness. These figures should be of considerable value to those modeling computer codes of shell-impact phenomena, because the actual shell contours can be readily compared with computer-generated contours.

The other three conclusions result from plotting parameters derived from measurements of these radiographs.

Thus, the second conclusion is that normalized crush height ($T/2R_o$, where T = crush height and $2R_o$ = external diameter before impact) varies directly with impact velocity for both materials (Figs. 3 and 4). The curves exhibit a noticeable offset because, as impact velocity approaches zero, $T/2R_o$ must approach 1.0. Nevertheless, crush height varied more linearly with velocity than did any other measurement.

Third, normalized radius of contact (ρ/R_o , where ρ is the radius of the shell impact surface in the impact plane) varies directly with impact velocity for both materials but appears independent of shell thickness for tantalum (Figs. 5 and 6). The data for all three thicknesses of tantalum shells clustered so tightly that one curve fit all points (Fig. 5), while a separate curve fit the data for each stainless steel shell thickness (Fig. 6). Interestingly, the fit of the curve to the tantalum data is almost as good as the fit of any one of the three curves to the stainless steel data. Even though both materials were annealed and have roughly the same yield points and Young's modulus, the stainless steel shells behaved more stiffly.

Fourth, normalized interior-fold radius (r/R_i , where r = interior radius of the fold and R_i = internal radius before impact) varies inversely with impact velocity and directly with shell thickness for stainless steel, but no clear relationship appears for tantalum (Fig. 7). For each stainless steel thickness, there is a clear relationship between r/R_i and impact velocity. In a similar plot for the tantalum shells, however, the data were scattered; therefore, the plot was eliminated.

COMMENTS

No active instrumentation was used in this study; instead, all data were derived from measurements of test specimens. The shells themselves were used in post-test measurement of major and minor diameters of both interior and exterior dots. These diameters coincided with the axes of dot height and dot

width measured before the test. The coincident axes of measurement simplified data comparison. Appendix B presents these raw data in a form that can be readily compared to computer-code calculations or fitted to a proposed failure theory.

These post-test measurements were as accurate as possible. The desired goal was accuracy to the nearest mil; however, there were physical limits. At times, the shell deformed so much that reliable dot measurement was not possible. At other times, the dots became smeared or blurred. In addition, a dot 1.5 mm in diameter before the test and 1.65 major diameter after the test actually extended 10%. Yet, if each diameter were mismeasured by 0.025 mm, a mil, this same extension could be measured as 6.7% or 13+%. These reasons help explain the wide scatter in data. Therefore, I consider the data in Appendix B useful in indicating very general trends, but not accurate enough to define clearly the variation in surface strain from point to point.

One question this study addressed was the maximum impact velocity a shell could withstand without leaking. Data indicated that the stainless steel shells, regardless of wall thickness, developed leaks after being subjected to impact velocities of 165-180 m/s. There was, however, no clear relationship between wall thickness and impact velocity. The thickest tantalum shell also developed a leak in this velocity range. For the two thinner tantalum shells ($R/t = 38$ and $R/t = 79$) there were insufficient data to draw any conclusions.

The deformation behavior of the two shell materials differed significantly. As mentioned previously, the stainless steel shells acted as stiffer units. Upon deforming, they formed smooth folds regardless of wall thickness. The impact surface had a circular perimeter with no sharp corners or edges. Only the thickest tantalum specimens ($R/t = 25$) folded in this manner. Those with a $R/t = 38$ formed smooth folds until impact velocities exceeded 100 m/s. In the upper velocity range, the impact surface was relatively flat and circular but had a rather sharp edge, as if the material were slumping under the impact load. The thinnest tantalum shell ($R/t = 79$) readily formed a concave impact surface with a pentagonal perimeter. As the impact velocities increased, a second pentagonal fold formed behind the first, producing a pattern similar to that seen on axially buckled cylinders. I suspect that these corners and edges act as stress concentrations and limit the impact velocity the shell could sustain. This observed deformation implied that the stainless steel shells begin buckling failure at a wall thickness of about $R/t = 79$, while the tantalum shells begin buckling failure at a wall thickness closer to $R/t = 38$.

In the beginning of the study, I modeled a few shell impact tests using a two-dimensional hydrodynamic computer code. The results approximated preliminary tests of shell contours and exterior surface strain measurements. These calculations indicated that interior surface strains were higher than those of the exterior surface and that principal strains within the shell wall were higher yet. These strains were manifested physically during the test, when the thick stainless steel shells ($R/t = 25$) began to rip from the inside out at impact velocities >160 m/s, even though the exterior surface strains were relatively low (~ 5 - 10%). This suggests that the exterior surface strain, while easy to monitor, is a relatively insensitive indicator of the maximum strain condition in the shell.

The calculations indicated that the maximum surface strains would easily exceed 10% . Strains of this magnitude preclude the use of electric resistance strain gages because they are useful up to a maximum of 5 - 6% . Etched grids have been used for strains greater than 5% ; however, accurate positioning and measurement of the grid are critical and time-consuming. For these reasons we selected a dot pattern. Note Figs. C.2 and C.3 in Appendix C. The dot pattern could be accurately positioned and inspected in less time than a cross-hatched grid, yet it could accommodate large strains. In actual practice the dot pattern was imperfect. Its shortcomings have been summarized in the results. A more accurate positioning and inspection procedure would probably not gain much, because the most important data would still be lost in the folds of the shell. A good method for obtaining accurate, large-strain measurements in a dynamic test would have been helpful.

A sophisticated computer routine fit curves to the data presented in Figs. 3-7. The form of the equations was intended to meet three criteria: A) be relatively simple, B) fit reasonably well, and C) meet appropriate boundary conditions. The equations chosen meet these criteria. From them one could, if desired, sketch the approximate deformed shape of a shell at a given impact velocity.

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REFERENCES

1. R. E. Morris, *Experimental Stress Analysis of Large Plastic Deformations in a Hollow Sphere Deformed by Impact against a Concrete Block*, NASA TMX-68270 (1973).
2. D. F. Haskell, "Large Impact Deformation Response of Spherical Shells," *AIAAJ* 8 (12), 2123-29 (1970).

Appendix A
Shell Deformation Data

Material: Annealed 304 stainless steel

R/t: 25

Wall thickness: 1.52 mm

R_i: 38.1 mm

Shell designation	Post-test condition	Impact velocity, m/s	H, mm	h, mm	ρ, mm	T, mm	r, mm
A	tight	88	22.6	9.14	32.0	62.2	5.08
B	tight	112	21.1	8.38	34.3	60.7	4.19
D	tight	158	16.26	8.38	38.35	55.9	2.41
C	tight	177	14.7	7.62	39.62	54.3	1.78
F	tight	184	14.0	6.35	39.9	53.6	1.78

Material: Annealed 304 stainless steel

R/t: 38

Wall thickness: 1.0 mm

R_i: 38.1 mm

Shell designation	Post-test condition	Impact velocity, m/s	H, mm	h, mm	ρ, mm	T, mm	r, mm
F	tight	65	25.1	9.65	29.34	64.26	4.37
A	tight	90	22.35	9.91	32.77	61.47	3.18
B	tight	122	20.83	8.38	34.92	59.94	2.18
E	ripped	174	14.73	9.65	37.34	53.85	2.56

Material: Annealed 304 stainless steel

R/t: 79

Wall thickness: 0.48 mm

R_i: 38.1 mm

Shell designation	Post-test condition	Impact velocity, m/s	H, mm	h, mm	ρ, mm	T, mm	r, mm
B	tight	28	30.23	7.37	22.6	68.83	4.95
A	tight	33	29.21	8.64	24.38	67.82	4.32
C	tight	55	24.38	10.41	28.57	63.0	3.18
D	tight	90	20.57	8.53	34.67	59.18	1.57
E	tight	117	11.68	5.59	37.72	50.29	0.79
F	leak (small)	171	2.29	6.35	39.62	40.89	0.60

Material: Annealed tantalum

R/t: 25

Wall thickness: 1.52 mm

R_i: 38.1 mm

Shell designation	Post-test condition	Impact velocity, m/s	H, mm	h, mm	ρ, mm	T, mm	r, mm
A	tight	84	21.1	7.11	34.92	60.7	2.56
F	tight	97	20.3	7.62	35.91	59.94	2.39
B	tight	117	17.55	9.14	37.9	57.15	2.18
E	tight	128	16.0	9.40	38.5	55.63	2.18
D	tight	143	14.7	7.62	40.28	54.36	1.40
C	leak	169	9.91	6.60	39.88	49.53	

Material: Annealed tantalum

R/t: 38

Wall thickness: 1.02 mm

R_i: 38.1 mm

Shell designation	Post-test condition	Impact velocity, m/s	H, mm	h, mm	ρ, mm	T, mm	r, mm
A	tight	58	25.1	9.5	30.56	64.3	2.97
B	tight	73	23.6	5.59	33.15	62.7	1.78
C	tight	104	20.3	2.79	36.9	59.44	
D	ripped	183	1.8	7.1	40.9		

Material: Annealed tantalum

R/t: 79

Wall thickness: 0.48 mm (0.019")

R_i: 38.1 mm (1.50")

Shell designation	Post-test condition	Impact velocity, m/s	H, mm	h, mm	ρ, mm	T, mm	r, mm
B	tight	28	26.42	11.4	27.38	65.0	3.56
C	tight	43	24.1	13.5	29.97	62.7	2.97
D	tight	61	20.8	12.7	31.24	59.4	2.97
E	tight	76	17.8	8.6	34.54	56.4	0.58
F	tight	116	9.1	5.6	38.51	47.7	

APPENDIX A. SHELL DEFORMATION DATA

Fig. A-1. Parameters of deformed shell contour. Values for these parameters are listed in the following tables.

APPENDIX B. DOT DISTORTION DATA

Fig. B-1. Shell reference system. Dot distortion data are listed in the following tables.

Test Number: A-25-SS

Shell mass: 231.6 g

Material: stainless steel

Sabot mass: 4571 g

Wall thickness: 1.5 mm

Impact velocity: 88 m/s

R/t: 25

Shell condition after test: leaktight

Impact plate: alumina

Surface interior path 1

Dot	ϕ_1	ϕ_2	Initial diameter (y_i), mm	Final diameter (y_f), mm	$\frac{y_f - y_i}{y_i}$	Initial diameter (x_i), mm	Final diameter (x_f), mm	$\frac{x_f - x_i}{x_i}$
1	81.6081	78.7240	1.9170	1.8953	-.0113	1.9700	1.8948	-.0382
2	71.5488	68.5441	1.9970	1.9131	-.0420	1.9840	1.9964	.0063
3	61.2495	58.4581	1.8554	1.3076	.0281	1.8816	1.9583	.0408
4	51.4860	48.5610	1.9421	1.6132	-.1694	1.9926	2.0879	.0478
5	41.3995	38.5031	1.9255	1.8724	-.0276	1.9149	2.0091	.0492
6	31.3221	28.3955	1.9457	1.9715	.0133	1.9169	1.9761	.0309
7	21.3642	18.4625	1.9295	1.9258	-.0019	1.9563	1.9914	.0179
8	11.1504	8.2418	1.9344	1.9283	-.0031	1.9571	1.9583	.0006
9	1.4069	-1.4208	1.8805	1.9665	.0457	1.8458	1.9990	.0830

Surface interior path 2

1	81.7784	78.8359	1.9560	1.9741	.0092	1.9436	1.9228	-.0107
2	71.6980	68.7833	1.9379	1.9258	-.0063	1.9301	1.9075	-.0117
3	61.5523	58.6054	1.9593	1.5126	-.2280	2.0178	2.2174	.0989
4	51.7191	48.6774	2.0222	1.6335	-.1922	2.0612	2.1793	.0573
5	41.6011	38.6012	1.9946	1.9461	-.0243	2.0455	2.0752	.0145
6	31.6896	28.5766	2.0699	1.9842	-.0414	2.0937	2.1666	.0348
7	21.4908	18.3748	2.0721	2.0478	-.0117	2.0196	1.9329	-.0429
8	11.6401	8.6918	1.9607	1.9283	-.0165	1.9474	2.0091	.0317

Surface exterior path 1

1	81.5487	78.9362	1.8061	1.7834	-.0126	1.8425	1.7577	-.0460
2	71.5527	68.9511	1.7987	1.7199	-.0438	1.8453	1.8517	.0034
3	61.5903	58.9690	1.8125	1.9063	.0517	1.9032	2.0066	.0543
4	51.6574	48.9924	1.8428	2.0989	.1390	1.8898	1.8847	-.0027
5	41.6211	39.0337	1.7893	1.9385	.0834	1.8804	1.9050	.0131
6	31.5713	28.9399	1.8185	1.5751	-.1339	1.7856	1.7196	-.0370
7	21.4867	18.8564	1.8177	1.7174	-.0552	1.8951	1.6891	-.1087
8	11.5226	8.7821	1.8959	1.6335	-.1384	1.9106	1.8390	-.0375
9	1.3855	-1.2836	1.8465	1.8089	-.0204	1.8420	1.7526	-.0485

Surface exterior path 2

1	81.6137	78.9659	1.8307	1.7580	-.0397	1.8519	1.8212	-.0166
2	71.6066	68.9477	1.8388	1.7479	-.0494	1.8951	1.8796	-.0082
3	61.6028	58.9373	1.8434	1.9627	.0648	1.8171	1.9202	.0568
4	51.5591	48.9446	1.8080	1.7243	-.0463	1.8146	1.7983	-.0090
5	41.5325	38.8764	1.8370	1.6513	-.1011	1.8605	1.7374	-.0662
6	31.4288	28.8044	1.8152	1.5649	-.1379	1.8232	1.6866	-.0750
7	21.5253	18.8695	1.8371	1.6792	-.0859	1.9131	1.7120	-.1052
8	11.4412	8.8088	1.8211	1.7072	-.0625	1.8745	1.7856	-.0474

Test number: B-25-SS

Shell mass: 230 g

Material: stainless steel

Sabot mass: 4635 g

Wall thickness: 1.5 mm

Impact velocity: 113 m/s

R/t: 25

Shell condition after test: leaktight

Impact plate: alumina

Surface interior path 1

Dot	ϕ_1	ϕ_2	Initial diameter (y_i), mm	Final diameter (y_f), mm	$\frac{y_f - y_i}{y_i}$	Initial diameter (x_i), mm	Final diameter (x_f), mm	$\frac{x_f - x_i}{x_i}$
1	82.2406	78.9784	2.1685	2.1724	.0018	2.0790	2.0752	-.0018
2	72.2146	68.8227	2.2549	2.2639	.0040	2.2197	2.4079	.0848
3	61.9656	58.7648	2.1279	1.5465	-.2732	2.0742	2.6111	.2589
4	51.9438	48.8388	2.0641	1.9207	-.0695	2.1552	2.4917	.1562
5	41.8192	38.6778	2.0883	1.9690	-.0571	2.0848	2.1742	.0429
6	31.5729	28.6671	1.9321	2.1647	.1204	2.0114	2.2098	.0986
7	21.8378	18.7403	2.0598	2.1190	.0287	2.1425	2.2250	.0385
8	11.6618	8.3166	2.2243	2.2715	.0212	2.3378	2.3927	.0235
9	1.0586	-2.0847	2.0903	2.3198	.1098	2.0046	2.2758	.1353

Surface interior path 2

1	80.9417	77.9170	2.0105	2.1266	.0577	2.0241	2.1387	.0566
2	71.2555	68.0211	2.1498	1.9868	-.0758	2.1620	2.0625	-.0461
3	60.8637	57.8815	1.9823	1.5491	-.2185	1.9698	2.6187	.3295
4	51.0952	48.0544	2.0212	1.8267	-.0963	1.9604	2.3012	.1739
5	40.8642	37.7173	2.0919	1.9512	-.0673	2.0432	2.2149	.0840
6	30.7493	27.5310	2.1395	2.1215	-.0084	2.1128	2.3597	.1169
7	20.8764	17.7042	2.1093	2.1749	.0311	2.1234	2.2809	.0742
8	11.0804	7.9380	2.0898	2.1469	.0274	2.0206	2.3038	.1402

Surface exterior path 1

1	81.4109	78.8193	1.7919	1.7428	-.0274	1.8283	1.8720	.0239
2	71.5607	68.9316	1.8178	1.7834	-.0189	1.8329	1.9202	.0477
3	61.5692	58.9265	1.8272	2.0221	.1067	1.8961	2.0879	.1011
4	51.6563	48.9646	1.8610			1.8651		
5	41.6514	38.9973	1.8352	1.6030	-.1265	1.8372	1.7094	-.0695
6	31.6615	28.9235	1.8935	1.6996	-.1024	1.8649	1.8593	-.0030
7	21.5994	18.9014	1.8662	1.8216	-.0239	1.8631	1.9380	.0402
8	11.5624	8.8263	1.8927	1.7606	-.0698	1.8636	1.6637	-.1073
9	1.5422	-1.0511	1.7938	1.8114	.0098	1.8044	1.7374	-.0372

Surface exterior path 2

1	81.8848	79.1698	1.8771	1.9283	.0273	1.9578	1.9406	-.0088
2	71.9805	69.2985	1.8542	1.8114	-.0231	1.8860	1.9075	.0114
3	61.9539	59.0409	2.0140	2.0920	.0387	2.1006	2.2022	.0484
4	52.0066	49.2810	1.8844	1.8643	-.0106	1.9317	1.9888	.0296
5	41.9472	39.1759	1.9162			1.9177		
6	31.9771	29.2857	1.8610	1.7834	-.0417	1.9017	1.9025	.0004
7	22.2939	19.4334	1.9785			1.9553		
8	12.1479	9.0354	2.1530			2.2730		

Test number: C-25-SS

Shell mass: 231 g

Material: stainless steel

Sabot mass: 4600 g

Wall thickness: 1.5 mm

Impact velocity: 177 m/s

R/t: 25

Shell condition after test: leaktight

Impact plate: steel, 16 rms finish

Surface interior path 1

Dot	ϕ_1	ϕ_2	Initial diameter (y_i), mm	Final diameter (y_f), mm	$\frac{y_f - y_i}{y_i}$	Initial diameter (x_i), mm	Final diameter (x_f), mm	$\frac{x_f - x_i}{x_i}$
1	82.2750	79.2715	1.9963	1.7860	-.1054	1.9233	2.0142	.0473
2	71.0844	68.3755	1.8005	.9353	-.4805	1.8832	2.1361	.1343
3	61.7645	58.9690	1.8581			1.9962		
4	51.7077	48.8135	1.9239	1.9715	.0248	1.9853	2.0295	.0223
5	41.8350	38.9323	1.9297	1.7606	-.0877	1.9223	1.9583	.0188
6	31.6110	28.8232	1.8534	1.8368	-.0089	1.8395	2.0091	.0922
7	21.6122	18.6386	1.9769	1.8419	-.0683	1.9215	2.0193	.0509
8	11.3901	8.5757	1.8714	1.9436	.0386	1.8758	1.8847	.0047
9	1.4283	-1.4272	1.8990	2.0198	.0637	1.9020	1.9583	.0296

Surface interior path 2

1	79.9990	77.9990	1.3299			1.7780		
2	72.3285	69.2733	2.0306	1.1637	-.4269	1.9327	2.2098	.1434
3	62.2395	59.3184	1.9415	1.6996	-.1246	1.8943	2.1133	.1156
4	52.4777	49.3138	2.1032	1.8063	-.1411	2.0307	2.1488	.0582
5	42.0511	39.3325	1.8072	1.7352	-.0398	1.9703	1.9025	-.0344
6	32.1257	29.1960	1.9478	1.7987	-.0765	1.9561	2.0853	.0661
7	22.2200	19.3045	1.9385	1.9131	-.0131	2.0302	1.9837	-.0229
8	12.1107	9.2502	1.9022	1.9359	.0178	2.0147	2.0345	.0098

Surface exterior path 1

1	81.9789	79.4595	1.7419	1.6081	-.0768	1.8357	1.8821	.0253
2	72.1707	69.5483	1.8131	1.9588	.0803	1.8524	2.1234	.1463
3	62.1539	59.5159	1.8239	1.5928	-.1267	1.8451	2.0904	.1330
4	52.0782	49.4508	1.8167	1.7072	-.0603	1.8222	1.9761	.0845
5	42.0428	39.4806	1.7717	1.6386	-.0751	1.8158	1.9355	.0659
6	31.9621	29.4171	1.7599	1.5954	-.0935	1.8461	1.8440	-.0011
7	21.9267	19.2986	1.8175	1.7707	-.0257	1.8354	1.8644	.0158
8	12.1332	9.3318	1.9376	1.8368	-.0520	1.8636	1.9152	.0277
9	1.7883	-.9158	1.8703	1.7733	-.0519	1.8232	1.8110	-.0067

Surface exterior path 2

1	81.2487	78.6837	1.7734	1.6742	-.0560	1.8252	1.9761	.0827
2	71.3338	68.7049	1.8176	2.1221	.1675	1.8672	2.2733	.2175
3	61.4559	58.7690	1.8578	1.7047	-.0824	1.9840	1.8999	-.0424
4	51.2963	48.7199	1.7815	1.5751	-.1159	1.7518	1.7805	.0164
5	41.3631	38.8364	1.7471	1.7072	-.0228	1.7887	1.8009	.0068
6	31.4199	28.7688	1.8333	1.6615	-.0937	1.8735	1.8440	-.0157
7	21.3350	18.7356	1.7977	1.7885	-.0051	1.8095	1.8517	.0233
8	11.2643	8.6021	1.8414	1.7987	-.0232	1.7732	1.7831	.0056

Test number: D-25-SS

Shell mass: 231 g

Material: stainless steel

Sabot mass: 4626 g

Wall thickness: 1.5 mm

Impact velocity: 158 m/s

R/t: 25

Shell condition after test: leaktight

Impact plate: alumina

Surface interior path 1

Dot	ϕ_1	ϕ_2	Initial diameter (y_i), mm	Final diameter (y_f), mm	$\frac{y_f - y_i}{y_i}$	Initial diameter (x_i), mm	Final diameter (x_f), mm	$\frac{x_f - x_i}{x_i}$
1	81.3920	78.6368	1.9308	1.8089	-.0120	1.9027	1.9025	-.0001
2	71.4113	68.4947	1.9382	.9777	-.4955	1.8816	1.5291	-.1874
3	61.2764	58.3926	1.9169	1.4785	-.2287	1.9423	1.9304	-.0061
4	51.1191	48.3777	1.8221	1.7962	-.0142	1.7970	1.9507	.0855
5	41.1920	38.3281	1.9036	1.8114	-.0484	1.8499	1.9710	.0655
6	30.9224	28.2235	1.7944	1.7707	-.0132	1.8151	1.9075	.0509
7	20.9967	18.2712	1.8125	1.8699	.0316	1.9274	2.0523	.0648
8	10.8685	7.9630	1.9323	2.1215	.0979	2.0701	2.1488	.0380
9	1.3750	-1.5916	1.9731	2.0453	.0366	1.8768	2.0193	.0759

Surface interior path 2

1		78.8048		1.7962		1.8699	1.9685	.0527
2	71.6555	68.8161	1.8871	1.3134	-.3040	1.9497	2.3546	.2077
3	61.6800	58.9098	1.8414	1.5446	-.1612	1.8639	2.0117	.0793
4	51.8088	49.0371	1.8422	1.7657	-.0415	1.8989	1.9990	.0527
5	41.6328	38.8123	1.8748	1.7834	-.0487	1.9106	1.9787	.0356
6	31.7357	28.7607	1.9776	1.9410	-.0185	1.9426	1.9710	.0146
7	21.7097	18.7311	1.9804	1.9461	-.0173	2.0147	1.9761	-.0192
8	11.7271	8.8304	1.9264	1.9512	.0129	2.1603	2.0472	-.0523

Surface exterior path 1

1	81.7353	79.1904	1.7590	1.6030	-.0887	1.7663	1.7678	.0009
2	71.9949	69.3574	1.8228	1.9788	.0856	1.9030	2.0396	.0718
3	61.9986	59.3884	1.8045	1.7204	-.0466	1.7843	1.6942	-.0505
4	52.0277	49.3527	1.8493	1.5293	-.1730	1.8278	1.4935	-.1829
5	41.9058	39.3706	1.7528	1.5598	-.1101	1.7828	1.7678	-.0084
6	31.9138	29.3207	1.7932	1.5725	-.1231	1.7709	1.7628	-.0046
7	21.8208	19.2309	1.7916	1.6945	-.0542	1.7869	1.5367	-.1400
8	11.7343	9.1868	1.7623			1.6673		
9	1.4880	-1.0608	1.7630	1.6742	-.0504	1.7414	1.7678	.0152

Surface exterior path 2

1	81.6809	79.1551	1.7462	1.5801	-.0951	1.9594	1.8237	-.0692
2	71.6491	69.1091	1.7559	1.9395	.1046	1.8623	2.0980	.1266
3	61.7898	59.2098	1.7836			1.7704		
4	51.7366	49.1052	1.8193			1.9182		
5	41.8025	39.2025	1.7976	1.5725	-.1252	1.7089	1.8009	.0538
6	31.5232	29.0463	1.7127			1.7752		
7	21.5400	18.9603	1.7841			1.8227		
8	11.6332	8.9271	1.8720			1.8077		

Test number: F-25-SS

Shell mass: 232 g

Material: stainless steel

Sabot mass: 4660 g

Wall thickness: 1.5 mm

Impact velocity: 184 m/s

R/t: 25

Shell condition after test: not leaktight

Impact plate: alumina

Surface interior path 1

Dot	ϕ_1	ϕ_2	Initial diameter (y_i), mm	Final diameter (y_f), mm	$\frac{y_f - y_i}{y_i}$	Initial diameter (x_i), mm	Final diameter (x_f), mm	$\frac{x_f - x_i}{x_i}$
1	81.4067	78.7823	1.7442	1.7758	.0181	1.8037	1.6053	-.1100
2	71.3619	68.7405	1.7422			1.7907		
3	61.2959	58.6856	1.7350			1.8245		
4	51.3060	48.6327	1.7772	1.6742	-.0580	1.7976	2.0091	.1177
5	41.4672	38.7184	1.8274	1.5751	-.1381	1.8105	1.7729	-.0208
6	31.1190	28.5655	1.6977	1.5420	-.0917	1.7884	1.7602	-.0158
7	21.2878	18.6539	1.7512	1.6742	-.0440	1.7841	1.9253	.0792
8	10.9326	8.3841	1.6948	1.7021	.0043	1.7610	1.7577	-.0019
9	1.1128	-1.4089	1.6769	1.7606	.0499	1.7323	1.7704	.0220

Surface interior path 2

1	81.6762	79.0195	1.7655	1.5776	-.1064	1.7485	1.8136	.0372
2	71.7666	69.1008	1.7716	.8443	-.5234	1.7874	1.3462	-.2468
3	61.6225	58.9395	1.7833	1.5191	-.1481	1.7719	1.9253	.0866
4	51.7921	49.1624	1.7480	1.5293	-.1251	1.8059	1.9710	.0914
5	41.6036	39.1187	1.6518	1.5852	-.0403	1.7544	1.9101	.0888
6	31.5029	28.8318	1.7757	1.8089	.0187	1.7445	1.8517	.0614
7	21.6139	18.8684	1.8256	1.7987	-.0147	1.7864	1.8110	.0138
8	11.6735	8.9052	1.8408	1.9207	.0434	1.8263	1.9583	.0723

Surface exterior path 1

1	81.2567	78.9134	1.6200	1.4404	-.1109	1.6269	1.6815	.0336
2	71.2835	69.0522	1.5426	1.5233	-.0125	1.5735	1.7882	.1364
3	61.3370	59.0531	1.5791			1.5611		
4	51.3857	49.0591	1.6088			1.6180		
5	41.4092	39.0495	1.6317	1.3565	-.1686	1.5773	1.5240	-.0338
6	31.3996	29.0593	1.6183	1.4175	-.1241	1.5936	1.3945	-.1250
7	21.3744	19.0589	1.6012			1.6398		
8	11.4665	8.8802	1.7886			1.7346		

Surface exterior path 2

1	81.6331	79.2376	1.6561	1.4150	-.1456	1.6858	1.7348	.0291
2	71.7174	69.1819	1.7529	1.9162	.0931	1.7297	1.9787	.1439
3	61.4464	59.1412	1.5939			1.6200		
4	51.5404	49.2563	1.5793			1.5911		
5	41.4147	39.0878	1.6089	1.5191	-.0558	1.5949	1.5316	-.0397
6	31.3613	29.0691	1.5851			1.5461		
7	21.4264	19.1306	1.5877			1.6383		
8	11.3299	9.0341	1.5876			1.6406		

Test number: A-38-SS

Shell mass: 149.5 g

Material: stainless steel

Sabot mass: 3000 g

Wall thickness: 1.0 mm

Impact velocity: 90 m/s

R/t: 38

Shell condition after test: leaktight

Impact plate: steel, 16 rms finish

Surface interior path 1

Dot	ϕ_1	ϕ_2	Initial diameter (y_i), mm	Final diameter (y_f), mm	$\frac{y_f - y_i}{y_i}$	Initial diameter (x_i), mm	Final diameter (x_f), mm	$\frac{x_f - x_i}{x_i}$
1	81.5987	78.3784	2.1405	2.1164	-.0112	2.1984	2.2073	.0040
2	71.4607	68.2661	2.1234	2.0758	-.0224	2.2014	2.1742	-.0123
3	61.3562	58.2004	2.0978	1.6665	-.2056	2.1234	2.1168	.0251
4	51.4185	48.1383	2.1802	1.6055	-.2636	2.1631	2.2504	.0404
5	41.4181	38.3667	2.0286	1.9919	-.0181	2.0960	2.1793	.0397
6	31.3282	28.2788	2.0275	1.9614	-.0326	2.0988	2.1514	.0251
7	21.6067	18.5620	2.0249	2.0656	.0201	2.0292	1.9329	-.0474
8	11.4571	8.2949	2.1033	2.0859	-.0083	2.0208	2.0574	.0181
9	1.8497	-1.2142	2.0382	2.1037	.0322	1.9972	2.0726	.0378

Surface interior path 2

1	81.5159	78.5784	1.9528	1.9792	.0135	2.0127	2.0396	.0134
2	71.5894	68.5786	2.0014	2.0605	.0295	2.0714	2.0853	.0067
3	61.7023	58.6242	2.0461	1.6106	-.2128	2.1237	2.2454	.0573
4	51.9291	48.9166	2.0028	1.5827	-.2098	2.0861	2.1920	.0508
5	41.7442	38.8381	1.9324	1.9436	.0058	2.0071	2.1082	.0504
6	31.8018	28.8771	1.9451	1.9919	.0241	1.9969	2.1158	.0595
7	22.1839	18.9742	2.1349	2.1088	-.0122	2.1443	2.1946	.0235
8	11.9621	8.9410	2.0099	2.1113	.0505	2.0665	2.1158	.0238

Surface exterior path 1

1	81.6745	78.6409	2.0705	2.0554	-.0073	2.0640	2.0498	-.0069
2	71.8107	68.6958	2.1259	2.0732	-.0248	2.0841	2.1234	.0189
3	61.7459	58.7209	2.0646	2.1749	.0534	2.1415	2.2581	.0544
4	51.8466	48.8183	2.0666	1.8953	-.0829	2.1394	2.0904	-.0229
5	41.8095	38.8256	2.0361	1.7733	-.1291	2.0871	2.0396	-.0228
6	31.8082	28.8743	2.0020	1.8317	-.0851	2.0551	1.9964	-.0286
7	21.8836	18.9175	2.0242	1.9283	-.0473	2.0533	2.0066	-.0228
8	11.9829	8.9310	2.0835	1.9283	-.0745	1.9855	1.9533	-.0162
9	1.8889	-1.0794	2.0254	1.3792	-.0228	1.9192	1.8364	-.0431

Surface exterior path 2

1	81.6537	78.7543	1.9792	2.0249	.0231	2.0645	2.0625	-.0010
2	71.6902	68.7213	2.0264	2.0275	.0005	2.1204	2.1565	.0170
3	61.6736	58.6890	2.0371	2.0453	.0040	2.0998	2.1869	.0415
4	51.8377	48.7588	2.1012	1.8343	-.1271	2.0790	2.0599	-.0092
5	41.8861	38.7881	2.1143	1.8267	-.1361	2.0683	2.0625	-.0028
6	31.8238	28.7844	2.0745	1.9944	-.0386	2.1133	2.0820	-.0144
7	21.8550	18.8042	2.0822	1.9741	-.0519	2.0787	2.0117	-.0323
8	11.9160	8.8149	2.1167	2.0300	-.0410	2.0759	2.0396	-.0175

Test number: B-38-SS

Shell mass: 149.5 g

Material: stainless steel

Sabot mass: 3000 g

Wall thickness: 1.0 mm

Impact velocity: 122 m/s

R/t: 38

Shell condition after test: leaktight

Impact plate: steel, 16 rms finish

Surface interior path 1

Dot	ϕ_1	ϕ_2	Initial diameter (y_i), mm	Final diameter (y_f), mm	$\frac{y_f - y_i}{y_i}$	Initial diameter (x_i), mm	Final diameter (x_f), mm	$\frac{x_f - x_i}{x_i}$
1	81.3031	78.4937	1.8673	1.8495	-.0095	1.9459	1.9304	-.0080
2	71.3866	68.5788	1.8662	1.7352	-.0702	1.9271	1.9126	-.0075
3	61.3070	58.4681	1.8869	1.3870	-.2649	1.9060	2.0599	.0808
4	49.9994	47.9994	1.3295			2.0320		
5	41.6225	38.7687	1.8976			1.9268		
6	31.3385	28.5149	1.8777	1.7707	-.0570	1.8971	1.9380	.0216
7	21.4714	18.6631	1.8679	1.8851	.0092	1.9088	1.9202	.0060
8	11.3776	8.5624	1.8728	1.7987	-.0396	1.9332	1.9380	.0025
9	1.5955	-1.1917	1.8543			1.8557		

Surface interior path 2

1	81.5970	78.6912	1.9317	1.9537	.0114	1.9454	1.9812	.0184
2	71.8441	68.9388	1.9312	1.8851	-.0239	1.9500	1.9787	.0147
3	62.1253	59.3081	1.8727	1.2498	-.3326	1.8786	2.0422	.0871
4	52.2696	49.5146	1.8315			1.8905		
5	42.3914	39.5848	1.8661			1.7945		
6	32.1935	29.4457	1.8272	1.7758	-.0281	1.8600	1.9050	.0242
7	22.2617	19.4353	1.8797	1.8648	-.0079	1.9561	1.9761	.0103
8	12.2507	9.4282	1.8776	1.8699	-.0041	1.9136	1.9202	.0035

Surface exterior path 1

1	82.0153	79.2690	1.8743	1.8953	.0112	1.8821	1.8796	-.0013
2	72.1010	69.4372	1.8181	1.7936	-.0135	1.8572	1.8821	.0134
3	61.9800	59.2356	1.8731	1.8317	-.0221	1.9113	2.0980	.0977
4	51.8838	49.1941	1.8358			1.8971		
5	41.7992	39.1714	1.7936	1.7784	-.0085	1.9289	2.0244	.0495
6	31.7288	28.9699	1.8832	1.7758	-.0570	1.9131	1.9304	.0090
7	21.6017	18.9314	1.8230	1.8978	.0411	1.8811	1.9456	.0343
8	11.5951	8.9438	1.8104	1.8724	.0342	1.8128	1.9152	.0565
9	1.3133	-1.1561	1.6862	1.8902	.1210	1.7346	1.8898	.0895

Surface exterior path 2

1	82.4125	79.7670	1.8059	1.8622	.0312	1.8603	1.8466	-.0074
2	72.5130	69.8699	1.8040	1.7428	-.0340	1.8235	1.8593	.0196
3	62.5689	59.8998	1.8219	1.8165	-.0030	1.8448	2.0422	.1070
4	52.4896	49.8249	1.8188	1.4531	-.2011	1.8481	2.0066	.0858
5	42.6203	39.9300	1.8363	1.7758	-.0329	1.8928	1.9456	.0279
6	32.4729	29.9060	1.7521	1.7860	.0193	1.8293	1.9355	.0580
7	22.3911	19.7872	1.7774	1.8546	.0434	1.8044	1.9456	.0783
8	12.3662	9.7357	1.7961	1.8521	.0312	1.8169	1.8644	.0261

Test number: E-38-SS
 Material: stainless steel
 Wall thickness: 1.0 mm
 R/t: 38

Shell mass: 150 g
 Sabot mass: 3030 g
 Impact velocity: 174 m/s
 Shell condition after test: ripped
 Impact plate: steel, 16 rms finish

Surface interior path 1

Dot	ϕ_1	ϕ_2	Initial diameter (y_i), mm	Final diameter (y_f), mm	$\frac{y_f - y_i}{y_i}$	Initial diameter (x_i), mm	Final diameter (x_f), mm	$\frac{x_f - x_i}{x_i}$
1	81.6434	78.6520	1.9889	1.4124	-.2898	1.9157	2.0955	.0939
2	71.4752	68.6388	1.8858	1.5700	-.1675	1.8545	2.1971	.1848
3	61.3189	58.5026	1.8728	1.4073	-.2485	1.8527	1.9406	.0474
4	51.2893	48.5949	1.7918	1.6437	-.0827	1.8936	1.9355	.0221
5	41.2984	38.5642	1.8185	1.5878	-.1269	1.8108	1.8821	.0394
6	31.0643	28.2916	1.8444	1.7936	-.0275	1.8443	1.8948	.0274
7	21.1947	18.4853	1.8025	1.7987	-.0021	1.8560	1.9152	.0319
8	11.2087	8.3541	1.8992	1.9461	.0247	1.8895	1.9482	.0311
9	1.2619	-1.4119	1.7792	1.8902	.0624	1.7549	1.9939	.1362

Surface interior path 2

1	81.4253	78.7587	1.7729	1.6284	-.0815	2.0013	1.9863	-.0075
2	71.4130	68.6863	1.8128	1.4810	-.1830	1.8715	2.0853	.1143
3	61.1912	58.5276	1.7711	1.2219	-.3101	1.8778	1.8085	-.0369
4	51.5638	48.7716	1.8566	1.6640	-.1037	1.8128	1.8466	.0186
5	41.3211	38.6514	1.7754	1.7504	-.0141	1.7643	1.9355	.0970
6	31.1718	28.5124	1.7688	1.7123	-.0319	1.7635	1.9279	.0932
7	21.2981	18.6775	1.7431	1.7885	.0260	1.7544	1.9812	.1293
8	11.4449	8.7657	1.7825	1.8953	.0633	1.7460	1.9253	.1027

Surface exterior path 1

1	81.2065	78.6815	1.7239	1.6030	-.0701	1.7154	1.8821	.0908
2	71.3730	68.8705	1.7087	1.7047	-.0023	1.6800	1.9025	.1324
3	61.4639	58.9048	1.7475	1.6284	-.0681	1.6782	1.8212	.0852
4	51.4288	48.8896	1.7338	1.4505	-.1634	1.6919	1.8542	.0959
5	41.4153	38.9956	1.6522	1.5191	-.0806	1.7925	1.8263	.0188
6	31.3382	28.9638	1.6214	1.4607	-.0991	1.7457	1.7958	.0287
7	21.3928	18.9275	1.6836	1.7428	.0352	1.8164	1.8593	.0236
8	11.3818	8.9093	1.6884	1.6665	-.0129	1.7851	1.7983	.0074
9	1.4608	-1.1267	1.7669	1.9114	.0252	1.7462	1.8161	.0400

Surface exterior path 2

1	81.2273	78.7795	1.6711	1.6030	-.0407	1.8161	1.8466	.0168
2	71.1994	68.7899	1.6450	1.5801	-.0394	1.7196	1.8948	.1019
3	61.2742	58.7454	1.7268	1.6538	-.0422	1.7335	1.9075	.1004
4	51.2938	48.7391	1.7444	1.4302	-.1801	1.8001	1.7958	-.0024
5	41.2853	38.7776	1.7124	1.6386	-.0431	1.7729	1.7577	-.0086
6	31.2693	28.7913	1.6921	1.5598	-.0782	1.7302	1.7348	.0026
7	21.2742	18.7209	1.7436	1.6767	-.0384	1.7523	1.8186	.0378
8	11.2887	8.7838	1.7107	1.7606	.0292	1.7335	1.8110	.0447

Test number: F-38-SS

Material: stainless steel

Wall thickness: 1.0 mm

R/t: 38

Shell mass: 152 g

Sabot mass: 3008 g

Impact velocity: 65 m/s

Shell condition after test: leaktight

Impact plate: steel, 16 rms finish

Surface interior path 1

Dot	ϕ_1	ϕ_2	Initial diameter (y_i), mm	Final diameter (y_f), mm	$\frac{y_f - y_i}{y_i}$	Initial diameter (x_i), mm	Final diameter (x_f), mm	$\frac{x_f - x_i}{x_i}$
1	81.7606	78.5543	2.1893	2.0986	-.0414	2.1405	2.2657	.0585
2	71.7830	68.5361	2.2171	2.2029	-.0064	2.1387	2.2885	.0701
3	61.7523	58.3323	2.3356	2.2613	-.0318	2.2451	2.3216	.0341
4	51.6849	48.4874	2.1838	1.8241	-.1647	2.2192	2.3978	.0805
5	41.6047	38.3184	2.2446	2.2232	-.0095	2.2075	2.3012	.0425
6	31.3657	28.1266	2.2126	2.1774	-.0159	2.1867	2.2962	.0501
7	21.6092	18.3287	2.2412	2.2207	-.0092	2.2106	2.2962	.0387
8	11.4746	9.1918	1.5597	2.2156	.4205	2.1732	2.2200	.0215
9	1.4922	-1.4528	2.0124	2.0453	.0163	1.8799	1.9660	.0458

Surface interior path 2

1	81.7828	78.5376	2.2157	2.1520	-.0287	2.0861	2.2149	.0617
2	71.7730	68.5638	2.1913	2.2156	.0111	2.1417	2.2758	.0626
3	61.6170	58.4487	2.1637	2.0783	-.0395	2.1072	2.3063	.0945
4	51.7477	48.7063	2.0770	1.1380	-.4521	2.0762	2.2860	.1011
5	41.5064	38.4114	2.1138	2.2995	.0879	2.1984	1.9202	-.1265
6	31.5376	28.4985	2.0758	2.2258	.0723	2.1115	1.9863	-.0593
7	21.5000	18.4989	2.0500	2.1139	.0312	2.1245	2.0371	-.0411
8	11.6090	8.6943	1.9915	2.0630	.0359	1.9860	2.0193	.0168

Surface exterior path 1

1	81.4306	78.5854	1.8919	1.9029	.0058	1.9296	1.9253	-.0022
2	71.6007	68.7294	1.9094	1.9588	.0259	1.8651	2.0142	.0799
3	61.6009	58.8190	1.8501	1.8826	.0175	1.9251	1.9964	.0371
4	51.6132	48.8938	1.8087	1.9359	.0704	1.8552	1.9736	.0638
5	41.7231	38.9995	1.8117	1.8648	.0293	1.8826	1.8237	-.0313
6	31.6051	28.8443	1.8367	1.7555	-.0442	1.8433	1.8872	.0238
7	21.6553	18.9028	1.8314	1.8597	.0155	1.9042	1.8644	-.0209
8	11.7265	8.9932	1.8188	1.8012	-.0096	1.8034	1.8644	.0338
9	1.5147	-1.2355	1.8302	1.9537	.0675	1.9134	1.8847	-.0150

Surface exterior path 2

1	81.3817	78.6412	1.8221	1.8902	.0374	1.9680	1.9710	.0015
2	71.5519	68.6969	1.8983	1.9741	.0399	1.9190	1.9787	.0311
3	61.4806	58.7017	1.8481	1.8724	.0132	1.8890	1.9914	.0542
4	51.6479	48.7149	1.9505	2.0630	.0577	1.9571	2.1031	.0746
5	41.5475	38.6642	1.9177	1.8292	-.0461	1.9479	1.9380	-.0051
6	31.5801	28.7344	1.8930	1.8495	-.0230	1.9101	1.9406	.0160
7	21.5206	18.6906	1.8827	1.8165	-.0352	1.9187	1.8923	-.0138
8	11.5671	8.6788	1.9219	1.8902	-.0165	2.0389	1.9609	-.0382

Test number: A-79-SS

Material: stainless steel

Wall thickness: 0.48 mm

R/t: 79

Shell mass: 74.8 g

Sabot mass: 4580 g

Impact velocity: 33 m/s

Shell condition after test: leaktight

Impact plate: steel, rms finish

Surface interior path 1

Dot	ϕ_1	ϕ_2	Initial diameter (y_i), mm	Final diameter (y_f), mm	$\frac{y_f - y_i}{y_i}$	Initial diameter (x_i), mm	Final diameter (x_f), mm	$\frac{x_f - x_i}{x_i}$
1	82.9070	79.8220	2.0032	2.0097	.0032	1.9350	2.0447	.0567
2	73.1349	70.1358	1.9644	1.9919	.0140	2.0452	2.0295	-.0077
3	63.2025	60.0473	2.1044	2.0834	-.0100	2.0358	2.0218	-.0069
4	53.3513	50.3266	2.0155	2.2359	.1094	2.0510	2.0599	.0043
5	43.2742	40.2823	1.9941	1.8749	-.0598	2.0409	2.0549	.0068
6	33.3718	30.2241	2.1097	2.0834	-.0125	2.0025	2.0066	.0020
7	23.4853	20.3695	2.0826	2.0783	-.0021	1.9324	2.0726	.0726
8	13.2423	10.3101	1.9534	2.0936	.0718	1.9670	2.1184	.0770
9	2.9069	-.1536	2.0360	2.1749	.0682	2.1074	2.0345	-.0346

Surface interior path 2

1	82.8100	79.9154	1.8878	1.9054	.0093	2.0858	2.0904	.0022
2	73.1877	70.2771	1.9398	1.9207	-.0098	1.9802	2.0777	.0493
3	63.6186	60.5117	2.0636	2.0910	.0133	2.0704	2.1057	.0171
4	53.9632	50.8185	2.0979	2.0020	-.0457	2.0470	2.1260	.0386
5	39.9995	37.9995	1.3299	1.8724	.4079	2.0320	1.9228	-.0538
6	32.4426	29.3388	2.0732	2.0961	.0110	2.0338	2.0523	.0091
7	23.9439	20.7322	2.1476	2.2003	.0246	2.1003	1.9812	-.0567
8	14.0129	10.9987	2.0066	2.1673	.0801	1.9545	2.1590	.1046

Surface exterior path 1

1	81.4623	78.5682	1.9147	2.0020	.0456	2.0376	2.1082	.0347
2	71.6982	68.7774	1.9856	2.0224	.0185	2.0071	1.9964	-.0053
3	61.6998	58.7137	2.0153	1.9715	-.0217	1.9787	2.0295	.0257
4	51.5635	48.6491	1.9677	1.9817	.0071	1.9187	1.9634	.0233
5	41.6222	38.7292	1.9556	2.0580	.0524	1.9467	2.0091	.0321
6	31.5538	28.5635	2.0322	1.9436	-.0436	1.9672	1.8669	-.0510
7	21.6956	18.7006	2.0266	1.9004	-.0623	2.2123	1.8948	-.1435
8	11.5729	8.6704	1.9568	1.8673	-.0457	2.0193	2.0015	-.0088
9	1.4311	-1.4194	1.9207	1.7529	-.0873	2.1326	1.8517	-.1317

Surface exterior path 2

1	81.6967	78.7120	1.9832	2.0122	.0146	1.9367	1.9406	.0020
2	72.0091	69.1319	1.9559	1.9334	-.0115	2.1717	1.9939	-.0819
3	62.0453	59.2042	1.9091	1.9639	.0287	1.9667	2.0091	.0216
4	51.7443	49.1319	1.7662	1.7860	.0112	1.8476	1.8415	-.0033
5	41.7870	39.2989	1.6873	1.9537	.1579	1.7163	1.8745	.0922
6	31.6060	28.9349	1.8140	1.8800	.0364	1.5083	1.8898	.2529
7	21.4225	18.6103	1.9025	1.8775	-.0131	1.8626	1.8669	.0023
8	11.1671	8.3021	1.9314	1.8597	-.0371	1.8496	1.8237	-.0140

Test number: B-79-SS

Shell mass: 75 g

Material: stainless steel

Sabot mass: 4582 g

Wall thickness: 0.48 mm

Impact velocity: 28 m/s

R/t: 79

Shell condition after test: leaktight

Impact plate: steel, 16 rms finish

Surface interior path 1

Dot	ϕ_1	ϕ_2	Initial diameter (y_i), mm	Final diameter (y_f), mm	$\frac{y_f - y_i}{y_i}$	Initial diameter (x_i), mm	Final diameter (x_f), mm	$\frac{x_f - x_i}{x_i}$
1	82.9875	79.8942	1.9871	2.0961	.0549	1.9830	2.0752	.0465
2	73.1407	70.2616	1.8974	2.0732	.0926	2.0411	2.0879	.0229
3	63.3731	60.3792	1.9916	2.1241	.0665	2.0221	2.1184	.0476
4	53.3743	50.3688	2.0008	2.0478	.0235	2.0510	2.1158	.0316
5	43.4800	40.4728	2.0070	1.9334	-.0367	1.9789	2.0803	.0512
6	32.9657	29.9574	2.0123	2.2156	.1010	2.1303	2.2149	.0397
7	23.1300			2.0859		1.9914	2.0498	.0293
8	12.9532	9.9896	1.9749	2.0936	.0601	1.9875	2.0599	.0364
9	3.2716	.0	2.1781	2.1851	.0032	2.0881	2.2200	.0631

Surface interior path 2

1	82.9631	79.9392	1.9773	1.9614	-.0081	2.3076	1.9533	-.1535
2	74.1754	70.8174	2.2196	2.1825	-.0167	2.0429	2.1692	.0618
3	63.8239	60.5798	2.1668	2.1520	-.0068	1.9870	2.2352	.1249
4	54.0015	50.8163	2.1161	2.1698	.0254	2.1303	2.2352	.0492
5	43.9283	40.9839	1.9649	1.7784	-.0949	2.0442	2.1590	.0562
6	34.0457	30.9527	2.0702	2.1520	.0395	2.2276	2.0828	-.0650
7	24.0147	21.0261	1.9981	2.1774	.0898	2.0632	2.1133	.0243
8	14.2826	11.1076	2.1145	2.1037	-.0051	2.0025	2.0371	.0173

Surface exterior path 1

1	81.6331	78.6354	1.9634	2.1495	.0948	2.1460	2.1742	.0131
2	71.9213	68.6913	2.2103	2.2054	-.0022	2.2222	2.2022	-.0090
3	62.0542	58.8351	2.1653	2.1978	.0150	2.0681	2.1615	.0452
4	52.0563	48.8749	2.1466	2.2003	.0250	2.1128	2.1666	.0255
5	42.0978	38.9878	2.1029	2.1495	.0221	2.0922	2.1819	.0429
6	31.7460	28.5277	2.1888	2.1622	-.0121	2.0719	1.9837	-.0425
7	22.1844	18.8617	2.2485	2.0783	-.0757	2.3444	2.1209	-.0953
8	11.7996	8.7079	2.0857	1.9334	-.0730	2.1979	2.0345	-.0743
9	1.5700	-1.5416	2.0987	2.0020	-.0461	2.0302	1.9964	-.0166

Surface exterior path 2

1	81.5309	78.7912	1.8253	2.0885	.1442	2.0724	2.1234	.0246
2	71.7705	68.7772	2.0352	2.1393	.0512	2.0930	2.2174	.0595
3	61.7081	58.7912	1.9609	2.0910	.0663	2.1024	2.1895	.0414
4	51.6102	48.6035	2.0285	1.9690	-.0293	1.9688	2.0345	.0334
5	41.2070	38.1726	2.0536	2.1546	.0491	1.9484	2.0879	.0716
6	31.7385	28.7010	2.0641	2.0198	-.0215	2.1204	2.0701	-.0237
7	21.0803	18.1734	1.9675	2.0097	.0214	2.0452	2.0345	-.0052
8	10.3713	7.3141	2.0617	2.1063	.0216	1.9347	2.0422	.0555

Test number: C-79-SS

Shell mass: 74.5 g

Material: stainless steel

Sabot mass: 4585 g

Wall thickness: 0.48 mm

Impact velocity: 55 m/s

R/t: 79

Shell condition after test: leaktight

Impact plate: stell, 16 rms finish

Surface interior path 1

Dot	ϕ_1	ϕ_2	Initial diameter (y_i), mm	Final diameter (y_f), mm	$\frac{y_f - y_i}{y_i}$	Initial diameter (x_i), mm	Final diameter (x_f), mm	$\frac{x_f - x_i}{x_i}$
1	81.9451	78.4907	2.2290	2.1749	-.0243	2.0668	2.2682	.0975
2	71.8121	68.5091	2.1871	2.2080	.0095	2.1687	2.1514	-.0080
3	61.7098	58.3720	2.2213	2.1088	-.0506	2.1153	2.3063	.0903
4	51.6949	48.3863	2.2057	1.9283	-.1258	2.0706	2.2276	.0758
5	41.6959	38.4426	2.1762	2.1444	-.0146	2.1013	2.1946	.0444
6	31.5482	28.2930	2.1786	2.1291	-.0227	2.1549	2.2098	.0255
7	21.8975	18.6278	2.1824	2.2995	.0536	2.2017	2.3978	.0891
8	11.7746	8.5577	2.1424	2.2334	.0425	2.1168	2.2352	.0559
9	1.9341	-1.0780	2.0051	2.3707	.1824	2.0401	2.3851	.1691

Surface interior path 2

1	81.8978	78.6268	2.1156	2.2003	.0400	2.1483	2.2809	.0617
2	71.9643	68.6361	2.1830	2.1876	.0021	2.0493	2.1590	.0535
3	61.8239	58.5240	2.1994	2.1978	-.0007	2.0925	2.1768	.0403
4	51.9396	48.6541	2.1886	2.0630	-.0574	2.0858	2.2581	.0826
5	41.6331	38.5817	2.0435	2.0656	.0108	2.1918	2.2758	.0384
6	31.7699	28.4727	2.2206	2.2613	.0184	2.0947	2.2428	.0707
7	21.6481	18.6339	2.0138	2.2410	.1128	1.9751	2.1488	.0880
8	11.9068	8.6732	2.1506	2.1139	-.0171	2.0127	2.1412	.0639

Surface exterior path 1

1	81.2837	78.1176	2.0773	1.9970	-.0387	2.1951	2.1107	-.0384
2	71.3727	68.1705	2.1817	2.1902	.0039	2.0815	2.2123	.0628
3	61.5345	58.2981	2.1796	2.1952	.0072	2.1892	2.2149	.0117
4	51.6191	48.3599	2.2015	2.3529	.0688	2.2672	2.3317	.0285
5	41.8875	38.3726	2.3819	2.1266	-.1072	2.2283	2.2250	-.0015
6	31.6349	28.2705	2.2852	2.1698	-.0505	2.1466	2.2174	.0330
7	21.7531	18.3284	2.3143	2.2054	-.0471	2.0991	2.1539	.0261
8	11.7732	8.5132	2.1979	2.1469	-.0232	2.2512	2.2276	-.0105
9	1.6289	-1.5794	2.1632	2.1546	-.0040	2.2875	2.2682	-.0084

Surface exterior path 2

1	81.2920	78.2237	2.0265	2.2690	.1196	2.0823	2.1438	.0295
2	71.5627	68.4908	2.0822	2.1063	.0116	2.0211	2.1666	.0720
3	61.4756	58.4120	2.0660	2.1393	.0355	2.1763	2.2123	.0166
4	51.9538	48.6383	2.2399	2.3910	.0675	2.1387	2.1361	-.0012
5	41.6900	38.3948	2.2351	2.0580	-.0793	2.1204	2.1717	.0242
6	31.7351	28.4788	2.2108	2.1037	-.0484	2.2146	2.1869	-.0125
7	21.7872	18.5073	2.2175	2.2130	-.0020	2.2370	2.2758	.0174
8	11.7346	8.6041	2.1077	2.2080	.0475	2.1374	2.2784	.0660

Test number: D-79-SS

Shell mass: 74.4 g

Material: stainless steel

Sabot mass: 4587 g

Wall thickness: 0.48 mm

Impact velocity: 90 m/s

R/t: 79

Shell condition after test: leaktight

Impact plate: steel, 16 rms finish

Surface interior path 1

Dot	ϕ_1	ϕ_2	Initial diameter (y_i), mm	Final diameter (y_f), mm	$\frac{y_f - y_i}{y_i}$	Initial diameter (x_i), mm	Final diameter (x_f), mm	$\frac{x_f - x_i}{x_i}$
1	81.7064	78.4232	2.1188	2.0427	-.0359	2.1140	2.0980	-.0076
2	71.7180	68.3677	2.2207	2.1902	-.0138	2.1311	2.1692	.0179
3	61.5711	58.2531	2.2047	1.4124	-.3593	2.1242	2.2987	.0821
4	51.7154	48.4599	2.1713	2.2817	.0508	2.1722	2.3216	.0688
5	41.7303	38.4401	2.1960	2.1368	-.0270	2.1580	2.2504	.0428
6	31.5693	28.3491	2.1526	2.1063	-.0215	2.2037	2.3495	.0662
7	21.8475	18.5067	2.2299	2.2207	-.0042	2.1148	2.1209	.0029
8	11.8940	8.5046	2.2554	2.3071	.0229	2.1067	2.2428	.0646
9	2.1852	-1.1653	2.2284	2.3834	.0696	2.3894	2.3038	-.0358

Surface interior path 2

1	81.7739	78.4943	2.1181	2.1419	.0112	2.0927	2.1514	.0280
2	71.8496	68.5019	2.2093	2.2486	.0178	2.1331	2.2073	.0348
3	61.6584	58.4709	2.1172	1.2142	-.4265	2.1720	2.2454	.0338
4	52.0546	48.5997	2.2976	2.4368	.0606	2.2073	2.4994	.1323
5	41.7642	38.4681	2.2066	2.0325	-.0789	2.2101	2.2250	.0068
6	31.6146	28.3794	2.1661	2.0707	-.0441	2.1196	2.1793	.0282
7	21.7642	18.5764	2.1252	2.0529	-.0340	2.1692	2.1514	-.0082
8	11.8929	8.6624	2.1483	2.1291	-.0089	2.1753	2.2225	.0217

Surface exterior path 1

1	81.5320	78.1401	2.4146	2.2893	-.0519	2.3736	2.3241	-.0209
2	71.6871	68.2950	2.3160	2.2359	-.0346	2.3518	2.2073	-.0615
3	61.7689	58.3334	2.3214	2.3453	.0103	2.3830	2.5375	.0648
4	51.6724	48.3188	2.2664	1.9665	-.1324	1.6863	2.4206	.4355
5	41.6928	38.5467	2.1296	1.8800	-.1172	1.7046	2.1006	.2323
6	31.7307	28.4646	2.2178	2.1266	-.0411	2.3180	2.1971	-.0522
7	21.6897	18.5553	2.1189	2.1190	.0000	2.2718	2.2225	-.0217
8	11.6221	8.4118	2.1632	2.2486	.0395	2.1659	2.2047	.0179
9	1.5994	-1.6775	2.2075	2.2435	.0163	2.2062	2.1996	-.0030

Surface exterior path 2

1	81.4551	78.0112	2.2668	2.3376	.0313	2.2576	2.3266	.0306
2	71.4046	68.1177	2.2378	2.0656	-.0769	2.1814	2.2377	.0259
3	61.6264	58.4329	2.1494	2.2232	.0343	2.1872	2.3927	.0939
4	51.8341	48.5552	2.2112	1.8470	-.1647	2.1460	2.2377	.0427
5	41.6834	38.4512	2.1942	2.0503	-.0656	2.2268	2.1412	-.0384
6	31.6451	28.4360	2.1761	1.9868	-.0870	2.1420	2.1946	.0245
7	21.5731	18.2942	2.2109	2.1393	-.0324	2.2184	2.2454	.0121
8	11.5557	8.3785	2.1404	2.1317	-.0041	2.0841	2.1488	.0311

Test number: E-79-SS

Shell mass: 74.8 g

Material: stainless steel

Sabot mass: 4585 g

Wall thickness: 0.48 mm

Impact velocity: 117 m/s

R/t: 79

Shell condition after test: leaktight

Impact plate: steel, 16 rms finish

Surface interior path 1

Dot	ϕ_1	ϕ_2	Initial diameter (y_i), mm	Final diameter (y_f), mm	$\frac{y_f - y_i}{y_i}$	Initial diameter (x_i), mm	Final diameter (x_f), mm	$\frac{x_f - x_i}{x_i}$
1	81.6423	78.7779	1.8395	2.0503	.1146	2.1379	2.2962	.0740
2	71.7349	68.5833	2.0825	1.8267	-.1229	2.1092	2.2174	.0513
3	61.7428	58.4076	2.2192	2.4470	.1027		2.3622	
4	51.7171	48.4274	2.1904	2.0859	-.0477	2.1161	2.3571	.1139
5	41.7036	38.5345	2.1160	2.0656	-.0238	2.1267	2.3419	.1012
6	31.5301	28.3346	2.1451	2.0986	-.0217	2.2494	2.2022	-.0210
7	21.8003	18.6156	2.1270	2.1876	.0285	2.1440	2.2123	.0319
8	11.6660	8.5652	2.0641	2.3681	.1473	1.9916	2.2631	.1363
9	1.9847	-1.1750	2.1023	2.2537	.0720	2.0808	2.2758	.0937

Surface interior path 2

1	80.8637	77.7140	2.0338	2.1902	.0769	2.0574	2.1615	.0506
2	70.8783	67.6700	2.1085	1.1609	-.4494	2.0904	2.2250	.0644
3	60.7789	57.5756	2.1263	2.0071	-.0560	2.0328	2.1615	.0634
4	50.9721	47.7588	2.1440	1.6106	-.2488	2.0381	2.3292	.1428
5	40.8306	37.5453	2.1987	2.0605	-.0628	2.0691	2.1387	.0336
6	30.6679	27.4266	2.1631	2.0859	-.0357	1.9848	2.1082	.0622
7	20.8564	17.5759	2.1875	1.9741	-.0975	2.0770	2.1184	.0199
8	10.9629	7.8527	2.0698	2.2893	.1061	2.1265	2.2581	.0619

Surface exterior path 1

1	81.5170	78.3973	2.0496	2.0071	-.0207	2.3099	2.1107	-.0862
2	71.5924	68.4708	2.1273	2.0681	-.0278	2.1082	2.1565	.0229
3	61.6361	58.5737	2.0645	.9551	-.5374	2.1021	2.1819	.0379
4	51.6252	48.5119	2.1026	2.0961	-.0031	2.0602	2.1869	.0615
5	41.6650	38.5881	2.0819	1.9029	-.0860	2.0613	2.1565	.0436
6	31.5532	28.4721	2.0942	2.0097	-.0404	2.0175	2.1285	.0396
7	21.6206	18.5495	2.0781	1.9232	-.0745	2.0940	2.1361	.0201
8	11.6074	8.5302	2.0745	2.0885	.0067	2.0424	2.1082	.0322
9	1.5900	-1.5983	2.1489	2.1469	-.0009	2.1991	2.1768	-.0102

Surface exterior path 2

1	82.3573	79.2212	2.0669	2.1113	.0215	2.0676	2.1463	.0381
2	72.4560	69.2858	2.1509	2.0630	-.0408	2.1008	2.1488	.0229
3	62.4484	59.3762	2.0684	2.1139	.0220	2.1212	2.1463	.0119
4	52.3704	49.4488	1.9752	1.8775	-.0495	2.1275	2.1234	-.0019
5	42.5870	39.4837	2.1067	2.1190	.0058	2.0594	2.1768	.0570
6	32.5265	29.5416	2.0219			2.0505	2.0955	.0219
7	22.5911	19.4300	2.1349	2.1012	-.0158	2.0229	2.1819	.0786
8	12.4984	9.3552	2.1236	2.1393	.0074	2.0742	2.1107	.0176

Test number: A-25-tA
 Material: tantalum
 Wall thickness: 1.5 mm
 R/t: 25

Shell mass: 484.5 g
 Sabot Mass: 9693 g
 Impact velocity: 84 m/s
 Shell condition after test: leaktight
 Impact plate: steel, 16 rms finish

Surface interior path 1

Dot	ϕ_1	ϕ_2	Initial diameter (y_i), mm	Final diameter (y_f), mm	$\frac{y_f - y_i}{y_i}$	Initial diameter (x_i), mm	Final diameter (x_f), mm	$\frac{x_f - x_i}{x_i}$
1	81.5017	78.7434	1.8379	1.6208	-.1181	1.8161	1.7602	-.0308
2	71.3838	68.9366	1.6308	1.4226	-.1277	1.6586	1.7221	.0383
3	61.3673	58.6034	1.8323	1.1250	-.3860	1.7424	1.7932	.0292
4	51.4577	48.9035	1.6960	1.4200	-.1627	1.6408	1.6840	.0263
5	41.3953	38.9481	1.6250	1.4099	-.1324	1.7196	1.6307	-.0517
6	31.3052	28.6232	1.7830	1.5598	-.1252	1.7120	1.7272	.0089
7	21.3539	18.8720	1.6490	1.5319	-.0710	1.6510	1.6840	.0200
8	11.3318	8.6596	1.7762	1.6513	-.0703	1.7272	1.6586	-.0397
9	1.4791	-1.0514	1.6823	1.5954	-.0517	1.7577	1.6840	-.0419

Surface interior path 2

1	81.4753	78.5573	1.9409	1.5903	-.1806	2.0015	1.7653	-.1180
2	71.4185	68.9047	1.6744	1.3768	-.1777	1.6307	1.6561	.0156
3	61.2645	58.7673	1.6575	1.0511	-.3658	1.6256	1.7932	.1031
4	51.5021	48.9230	1.7129	1.4937	-.1279	1.7018	1.8440	.0836
5	41.3842	38.8203	1.6994	1.5878	-.0657	1.6231	1.7247	.0626
6	31.3177	28.7982	1.6735	1.4810	-.1150	1.6383	1.6104	-.0171
7	21.3289	18.8053	1.6768	1.5928	-.0501	1.5926	1.6510	.0367
8	11.3637	8.8735	1.6557	1.5954	-.0364	1.6459	1.6256	-.0123

Surface exterior path 1

1	81.3059	78.7159	1.7953	1.5547	-.1340	1.8364	1.7577	-.0429
2	71.5630	68.8977	1.8440	1.6513	-.1045	1.7780	1.9685	.1071
3	61.5214	58.9478	1.7830	1.6403	-.0800	1.7602	1.8821	.0693
4	51.5896	48.9883	1.7990	1.6081	-.1061	1.8237	2.1539	.1811
5	41.6786	39.0981	1.7824	1.4836	-.1677	1.8212	1.8491	.0153
6	31.5788	29.0316	1.7623	1.4455	-.1798	1.6967	1.6866	-.0060
7	21.5928	19.0706	1.7435	1.5191	-.1287	1.7018	1.6713	-.0179
8	11.6596	9.1485	1.7359	1.5369	-.1146	1.7043	1.6078	-.0566
9	1.3083	-1.1430	1.6945	1.6869	-.0045	1.7958	1.7983	.0014

Surface exterior path 2

1	81.3905	78.8420	1.7670	1.6411	-.0712	1.7932	1.7374	-.0312
2	71.4685	68.7366	1.8894	1.4785	-.2175	1.7907	1.8263	.0199
3	61.3909	58.9062	1.7156	1.5809	-.0785	1.7399	1.8593	.0686
4	51.4021	48.9049	1.7294	1.4150	-.1818	1.7831	1.7602	-.0128
5	41.3703	38.9731	1.6576	1.4150	-.1464	1.6739	1.7120	.0228
6	31.6301	28.8371	1.9295	1.6589	-.1403	1.8415	1.7958	-.0248
7	21.4261	18.9581	1.7059	1.5039	-.1184	1.6942	1.7145	.0120
8	11.5651	8.7957	1.9145	1.6462	-.1401	1.8237	1.8136	-.0056

Test number: B-25-tA
 Material: tantalum
 Wall thickness: 1.5 mm
 R/t: 25

Shell mass: 483.5 g
 Sabot mass: 9680 g
 Impact velocity: 118 m/s
 Shell condition after test: leaktight
 Impact plate: steel, 16 rms finish

Surface interior path 1

Dot	ϕ_1	ϕ_2	Initial diameter (y_i), mm	Final diameter (y_f), mm	$\frac{y_f - y_i}{y_i}$	Initial diameter (x_i), mm	Final diameter (x_f), mm	$\frac{x_f - x_i}{x_i}$
1	81.5614	78.8851	1.7755	1.4455	-.1859	1.7704	1.6561	-.0646
2	71.5005	68.8949	1.7291	1.0821	-.3742	1.6891	1.7704	.0481
3	61.3323	58.6673	1.7693			1.6942	1.8288	.0795
4	51.4341	48.6605	1.8417	1.5115	-.1793	1.7882	1.9380	.0838
5	41.3578	38.7842	1.7093	1.4480	-.1529	1.6891	1.7424	.0316
6	31.1999	28.6316	1.7060	1.4937	-.1244	1.7729	1.6281	-.0817
7	21.3553	18.6334	1.8075	1.6538	-.0850	1.7907	1.7272	-.0355
8	11.2485	8.5027	1.8248	1.7529	-.0394	1.7323	1.7094	-.0132
9	1.3472	-1.3836	1.8155	1.8139	-.0008	1.8415	1.7983	-.0234

Surface interior path 2

1	81.3184	78.6073	1.8028	1.4912	-.1728	1.7958	1.7780	-.0099
2	71.3310	68.6797	1.7631	1.1380	-.3545	1.7805	1.9431	.0913
3	61.2131	58.5909	1.7437			1.7501		
4	51.3299	48.7299	1.7287	1.4810	-.1433	1.7678	1.8542	.0489
5	41.1717	38.4898	1.7831	1.4759	-.1723	1.8034	1.7955	-.0042
6	31.1315	28.3052	1.8788	1.6538	-.1197	1.8161	1.7399	-.0420
7	21.0803	18.3553	1.8115	1.6716	-.0772	1.8085	1.7247	-.0463
8	11.2360	8.4541	1.8493	1.6894	-.0864	1.7831	1.7094	-.0413

Surface exterior path 1

1	81.5503	78.6934	1.9756	1.8038	-.0870	1.9152	1.9329	.0093
2	71.4699	68.9380	1.7509	1.6767	-.0424	1.7374	1.9253	.1082
3	61.5770	58.9715	1.8046			1.7551		
4	51.5563	48.9605	1.7928	1.3514	-.2462	1.7272	1.8085	.0471
5	41.6134	39.0967	1.7402	1.5090	-.1329	1.6586	1.6764	.0107
6	31.5165	29.0538	1.7025	1.4251	-.1629	1.7034	1.6408	-.0401
7	21.6303	19.0720	1.7675	1.5446	-.1261	1.6408	1.6408	.0
8	11.5568	9.0707	1.7180	1.5522	-.0965	1.7602	1.6942	-.0375
9	1.5830	-1.1778	1.9085	1.6437	-.1388	1.9456	1.7297	-.1110

Surface exterior path 2

1	81.2892	78.7004	1.7908	1.6894	-.0566	1.7704	1.7755	.0029
2	71.3435	68.7699	1.7803	1.5776	-.1138	1.8339	1.9482	.0623
3	61.3048	58.7534	1.7648	1.3541	-.2327	1.7704	2.0625	.1650
4	51.3007	48.8924	1.6633	1.6259	-.0225	1.8440	1.8237	-.0110
5	41.2967	38.7037	1.7931	1.6284	-.0919	1.7882	1.6459	-.0795
6	31.3121	28.7746	1.7491	1.8800	.0749	1.7882	1.8745	.0483
7	21.2678	18.6817	1.7869	1.6615	-.0702	1.7628	1.6561	-.0605
8	11.2526	8.7846	1.7056	1.6691	-.0214	1.6180	1.6510	.0204

Test number: D-25-tA
 Material: tantalum
 Wall thickness: 1.5 mm
 R/t: 25

Shell mass: 482.8 g
 Sabot mass: 9725 g
 Impact velocity: 143 m/s
 Shell condition after test: leaktight
 Impact plate: steel, 16 rms finish

Surface interior path 1

Dot	ϕ_1	ϕ_2	Initial diameter (y_i), mm	Final diameter (y_f), mm	$\frac{y_f - y_i}{y_i}$	Initial diameter (x_i), mm	Final diameter (x_f), mm	$\frac{x_f - x_i}{x_i}$
1	81.6239	79.0379	1.7237	1.4404	-.1644	1.6815	1.7450	.0378
2	71.6796	69.0324	1.7644	.8103	-.5408	1.7526	1.9202	.0957
3	61.5353	58.9548	1.7163	1.4480	-.1563	1.7450	2.0549	.1776
4	51.5493	48.9494	1.7289	1.5852	-.0831	1.7450	1.8745	.0742
5	41.5831	38.8939	1.7903	1.5979	-.1074	1.7272	1.7958	.0397
6	31.4510	28.8121	1.7531	1.5852	-.0958	1.6789	1.6840	.0030
7	21.6011	18.9484	1.7628	1.6869	-.0431	1.6967	1.7120	.0090
8	11.4568	8.8457	1.7358	1.7301	-.0033	1.7145	1.7297	.0089
9	1.6639	-.9083	1.7102	1.7352	.0146	1.6942	1.7526	.0345

Surface interior path 2

1	81.4476	78.8976	1.6998	1.5700	-.0764	1.7551	1.6662	-.0507
2	71.4060	68.8227	1.7175	.8357	-.5134	1.6637	1.8161	.0916
3	61.2450	58.5840	1.7726	1.3845	-.2190	1.7831	2.0269	.1368
4	51.4577	48.8285	1.7483	1.5242	-.1282	1.8313	1.9863	.0846
5	41.2592	38.6620	1.7248	1.6437	-.0470	1.7983	1.8847	.0480
6	31.4149	28.6357	1.8494	1.6843	-.0893	1.7374	1.8821	.0833
7	21.3469	18.6817	1.7709	1.6259	-.0819	1.7272	1.7729	.0265
8	11.2971	8.7041	1.7243	1.7631	.0225	1.6662	1.7120	.0274

Surface exterior path 1

1	81.2976	78.8031	1.7259	1.5268	-.1154	1.8161	1.8237	.0042
2	71.5574	68.9533	1.8020	1.3768	-.2359	1.7704	1.3767	-.2224
3	61.5200	59.0117	1.7350			1.6993		
4	51.5785	49.0146	1.7730			1.7551		
5	41.3620	39.0814	1.5790			1.7424		
6	31.5357	29.0746	1.7012			1.7501		
7	21.5039	19.1636	1.6188	1.6081	-.0066	1.5977	1.6027	.0032
8	11.6290	9.1374	1.7225	1.6945	-.0162	1.6307	1.6840	.0327
9	1.2958	-1.0680	1.6343	1.7580	.0757	1.6256	1.5443	-.0500

Surface exterior path 2

1	81.3309	78.7337	1.7968	1.6360	-.0895	1.8593	1.9837	.0669
2	71.2282	68.9088	1.6037	1.4073	-.1225	1.5773	1.7628	.1176
3	61.3353	58.7909	1.7602	1.7580	-.0012	1.7399	1.9482	.1197
4	51.2646	48.7744	1.7221			1.7678		
5	41.2481	38.8426	1.6647			1.5138		
6	31.1468	28.7802	1.6378	1.8419	.1247	1.6993	1.9075	.1226
7	21.1136	18.9067	1.5254	1.4810	-.0291	1.6027	1.6561	.0333
8	11.1179	8.8318	1.5805	1.5725	-.0050	1.6942	1.7475	.0315

Test number: E-25-tA
 Material: tantalum
 Wall thickness: 1.5 mm
 R/t: 25

Shell mass: 483 g
 Sabot mass: 9718 g
 Impact velocity: 129 m/s
 Shell condition after test: leaktight
 Impact plate: steel, 16 rms finish

Surface interior path 1

Dot	ϕ_1	ϕ_2	Initial diameter (y_i), mm	Final diameter (y_f), mm	$\frac{y_f - y_i}{y_i}$	Initial diameter (x_i), mm	Final diameter (x_f), mm	$\frac{x_f - x_i}{x_i}$
1	81.6406	79.1462	1.6587	1.3997	-.1561	1.6662	1.7196	.0320
2	71.6685	69.2255	1.6271	1.0161	-.3755	1.6561	1.8898	.1411
3	61.6756	59.1173	1.7034	1.5852	-.0694	1.6358	1.8745	.1460
4	51.6688	49.3146	1.5672	1.3235	-.1555	1.6434	1.8440	.1221
5	41.6842	39.3314	1.5641	1.4023	-.1035	1.5697	1.6104	.0259
6	31.6038	29.1413	1.6371	1.3921	-.1497	1.6180	1.6053	-.0078
7	21.7081	19.2984	1.6018	1.5014	-.0627	1.5215	1.4935	-.0184
8	11.5887	9.1429	1.6258	1.6487	.0141	1.6205	1.5189	-.0627
9	1.9250	-.7347	1.7680	1.6970	-.0401	1.6764	1.6586	-.0106

Surface interior path 2

1	81.7267	78.7254	1.9959	1.4124	-.2924	1.8059	1.7780	-.0155
2	71.5130	68.5811	1.9494	.9936	-.4903	1.7094	1.9761	.1560
3	61.4437	58.9673	1.6466			1.6485	1.8694	.1341
4	51.6146	49.1508	1.6402	1.4709	-.1033	1.7297	1.8237	.0543
5	41.4647	38.9745	1.6581	1.4200	-.1436	1.6916	1.7170	.0150
6	31.2621	28.8649	1.5927	1.4455	-.0924	1.6256	1.6383	.0078
7	21.5053	18.8359	1.7750	1.7047	-.0396	1.8288	1.8644	.0194
8	11.4637	9.0235	1.6216	1.6411	.0121	1.6815	1.7043	.0136

Surface exterior path 1

1	81.3698	78.6698	1.8708	1.6716	-.1065	1.8339	1.7755	-.0319
2	71.3019	68.9519	1.6247	1.6843	.0367	1.6002	1.7018	.0635
3	61.4506	59.0173	1.6853	1.3616	-.1921	1.7069	1.6485	-.0342
4	51.5535	49.1244	1.6793			1.7907		
5	41.6411	39.2481	1.6544	1.6945	.0242	1.6891	1.7069	.0105
6	31.5440	29.2843	1.5635	1.5369	-.0170	1.5900	1.5342	-.0351
7	21.6483	19.2678	1.6454	1.6487	.0020	1.6713	1.6764	.0030
8	11.5707	9.2846	1.5806	1.5522	-.0180	1.6332	1.5088	-.0762
9	1.7639	-1.0292	1.9311	1.7657	-.0857	1.8288	1.7704	-.0319

Surface exterior path 2

1	81.0684	78.6768	1.6540	1.6106	-.0262	1.6256	1.6205	-.0031
2	71.1769	68.7699	1.6675	1.7470	.0477	1.6027	1.8212	.1363
3	61.3770	58.8479	1.7494	1.7479	-.0009	1.6459	1.6383	-.0046
4	51.1757	48.8646	1.5982	1.2117	-.2418	1.6104	1.3589	-.1562
5	41.2550	38.8787	1.6438			1.6129		
6	31.2357	28.8094	1.6766	1.6310	-.0272	1.6688	1.7323	.0381
7	21.1622	18.8303	1.6115	1.6640	.0326	1.6154	1.7247	.0676
8	11.1471	8.8791	1.5683	1.5649	-.0022	1.6104	1.5062	-.0647

Test number: F-25-tA
 Material: tantalum
 Wall thickness: 1.5 mm
 R/t: 25

Shell mass: 481 g
 Sabot mass: 9720 g
 Impact velocity: 97 m/s
 Shell condition after test: leaktight
 Impact plate: steel, 16 rms finish

Surface interior path 1

Dot	ϕ_1	ϕ_2	Initial diameter (y_i), mm	Final diameter (y_f), mm	$\frac{y_f - y_i}{y_i}$	Initial diameter (x_i), mm	Final diameter (x_f), mm	$\frac{x_f - x_i}{x_i}$
1	81.2684	78.5809	1.7873	1.6513	-.0761	1.7348	1.7932	.0337
2	71.2144	68.5811	1.7543	1.4277	-.1862	1.7526	1.8491	.0551
3	61.0867	58.4895	1.7240	1.1091	-.3567	1.7399	2.0269	.1650
4	51.0313	48.4230	1.7340	1.6691	-.0374	1.7526	1.9177	.0942
5	41.0717	38.3523	1.8098	1.6640	-.0806	1.7983	1.8745	.0424
6	30.8010	28.1705	1.7487	1.6665	-.0470	1.7958	1.8313	.0198
7	20.9220	18.2650	1.7663	1.6970	-.0392	1.7678	1.7805	.0072
8	10.8068	8.0985	1.8003	1.7987	-.0009	1.8212	1.7983	-.0126
9	.8792	-1.5708	1.6286	1.7911	.0998	1.7272	1.8237	.0559

Surface interior path 2

1	81.2809	78.7018	1.7162	1.7072	-.0052	1.6739	1.8440	.1017
2	71.3685	68.7713	1.7277	1.3743	-.2046	2.0142	1.6993	-.1564
3	61.2478	58.6367	1.7343	1.1515	-.3360	1.8212	1.9482	.0697
4	51.2729	48.8535	1.6089	1.5878	-.0132	1.6662	1.7094	.0259
5	41.0772	38.6648	1.6041	1.4937	-.0688	1.7196	1.7424	.0133
6	31.1593	28.4677	1.7882	1.6742	-.0638	1.7526	1.7424	-.0058
7	21.1844	18.5234	1.7680	1.7606	-.0042	1.8059	1.7729	-.0183
8	11.2582	8.5902	1.7729	1.7936	.0117	1.7170	1.7628	.0266

Surface exterior path 1

1	81.1976	78.6754	1.7445	1.4810	-.1510	1.7602	1.7856	.0144
2	71.3144	68.7644	1.7638	1.4937	-.1531	1.7272	1.8694	.0824
3	61.3978	58.7354	1.8331	1.7104	-.0669	1.7678	2.0345	.1509
4	51.2938	48.8591	1.6787	1.4429	-.1404	1.7170	1.8567	.0814
5	41.3370	38.7467	1.7887	1.5776	-.1180	1.7932	1.8136	.0113
6	31.2579	28.7191	1.7547	1.7250	-.0169	1.7069	1.7297	.0134
7	21.2775	18.7359	1.7566	1.7097	-.0267	1.7526	1.6205	-.0754
8	11.3387	8.7013	1.8224	1.7428	-.0437	1.8339	1.8288	-.0028
9	1.2680	-1.3944	1.8400	1.6665	-.0943	1.8364	1.7983	-.0207

Surface exterior path 2

1	81.3670	78.7837	1.7909	1.5115	-.1560	1.7653	1.6129	-.0863
2	71.3907	68.8463	1.7631	1.4480	-.1787	1.6485	1.7958	.0894
3	61.2673	58.7784	1.7211	1.6999	-.0123	1.6789	1.8009	.0726
4	51.3313	48.7702	1.7684	1.2651	-.2846	1.7221	1.7907	.0398
5	41.2939	38.7023	1.7898	1.5369	-.1413	1.7399	1.7577	.0102
6	31.1927	28.7524	1.6865	1.4734	-.1264	1.6891	1.6485	-.0241
7	21.1317	18.6456	1.7163	1.4531	-.1534	1.7424	1.6688	-.0423
8	11.0776	8.6374	1.6859	1.5598	-.0748	1.7145	1.7297	.0089

Test number: A-38-tA
 Material: tantalum
 Wall thickness: 1.0 mm
 R/t: 38

Shell mass: 318.3 g
 Sabot mass: 9200 g
 Impact velocity: 58 m/s
 Shell condition after test: leaktight
 Impact plate: steel, 16 rms finish

Surface interior path 1

Dot	ϕ_1	ϕ_2	Initial diameter (y_i), mm	Final diameter (y_f), mm	$\frac{y_f - y_i}{y_i}$	Initial diameter (x_i), mm	Final diameter (x_f), mm	$\frac{x_f - x_i}{x_i}$
1	81.7851	79.2004	1.7186			1.8009		
2	71.8560	69.2547	1.7297	1.7148	-.0086	1.7729	1.8745	.0573
3	61.6714	58.9990	1.7770	1.8267	.0280	1.8313	1.8618	.0166
4	51.7938	48.9188	1.9116	1.4767	-.2275	1.8034	2.2022	.2211
5	41.6870	38.9489	1.8206	2.1037	.1555	1.8390	2.2022	.1975
6	31.6343	28.8774	1.8330	1.8190	-.0076	1.8034	1.8898	.0479
7	21.7081	18.9359	1.8432	2.2461	.2186	1.8110	2.3724	.3100
8	11.4137	8.9818	1.6170	1.6920	.0463	1.7196	1.6916	-.0162
9	1.3569	-1.3083	1.7722			1.7882		

Surface interior path 2

1	81.7948	78.9659	1.8810	2.0351	.0819	1.7755	2.1768	.2260
2	71.5574	69.0047	1.6974	1.9665	.1585	1.8186	1.8821	.0349
3	61.5228	58.7590	1.8378	1.9080	.0382	1.7577	1.8263	.0390
4	51.5841	49.0049	1.7149	1.4482	-.1555	1.7348	1.8872	.0878
5	41.4164	38.8051	1.7362	1.8343	.0565	1.7170	1.7882	.0414
6	31.3302	28.6327	1.7935	1.8317	.0213	1.8186	1.9075	.0489
7	21.2942	18.6720	1.7436	1.7758	.0185	1.7374	1.7856	.0278
8	11.3329	8.7374	1.7259	1.7784	.0304	1.6459	1.7729	.0772

Surface exterior path 1

1	81.2753	78.7115	1.7505	1.7047	-.0262	1.7577	1.7170	-.0231
2	71.5852	68.6755	1.9866	1.8470	-.0703	1.9761	1.8974	-.0398
3	62.0353	58.9020	2.1392	1.9893	-.0701	1.9533	1.9152	-.0195
4	51.7604	48.9285	1.9310	1.8976	-.0173	1.9228	1.9279	.0026
5	41.5606	39.1120	1.6698	1.4683	-.1207	1.6688	1.7247	.0335
6	31.4926	29.0802	1.6455	1.4759	-.1030	1.6561	1.7043	.0291
7	21.4025	18.9470	1.6753	1.5827	-.0553	1.6205	1.5469	-.0455
8	11.4762	8.9971	1.6915	1.5852	-.0628	1.6002	1.6256	.0159
9	1.3458	-1.2347	1.7617	1.7199	-.0237	1.6459	1.6891	.0262

Surface exterior path 2

1	81.3003	78.8379	1.6812	1.7529	.0427	1.7526	1.6104	-.0812
2	71.4074	68.8699	1.7355	1.7987	.0364	1.6688	1.7120	.0259
3	61.3214	58.6965	1.7922	1.7097	-.0460	1.7856	1.8085	.0128
4	51.1368	48.6730	1.6821	1.8604	.1060	1.5977	1.7120	.0715
5	41.0384	38.6176	1.6508	1.5827	-.0412	1.6434	1.7120	.0417
6	31.0565	28.5621	1.7027	1.5801	-.0720	1.7069	1.7043	-.0015
7	20.9747	18.4650	1.7131	1.6081	-.0613	1.6764	1.6789	.0015
8	10.9901	8.5679	1.6535	1.6564	.0017	1.6256	1.6205	-.0031

Test number: C-38-tA
 Material: tantalum
 Wall thickness: 1.0 mm
 R/t: 38

Shell mass: 318.1 g
 Sabot mass: 9193 g
 Impact velocity: 104 m/s
 Shell condition after test: leaktight
 Impact plate: steel, 16 rms finish

Surface interior path 1

Dot	ϕ_1	ϕ_2	Initial diameter (y_i), mm	Final diameter (y_f), mm	$\frac{y_f - y_i}{y_i}$	Initial diameter (x_i), mm	Final diameter (x_f), mm	$\frac{x_f - x_i}{x_i}$
1	81.7295	79.0948	1.7526	1.6615	-.0520	1.7424	1.7780	.0204
2	71.7616	69.0699	1.7935	1.7631	-.0169	1.7348	1.7018	-.0190
3	61.7131	59.0520	1.7700			1.8669	1.9660	.0531
4		49.1063		1.7377		1.8669	1.9380	.0381
5	41.8647	39.2009	1.7717	1.6691	-.0579	1.7501	1.7882	.0218
6	31.6676	29.0955	1.7108	1.5979	-.0660	1.7247	1.7247	.0
7	21.7469	19.1275	1.7421	1.7072	-.0200	1.7043	1.6434	-.0358
8	11.6943	9.0179	1.7798	1.8165	.0206	1.7501	1.7704	.0116
9	1.5778	-1.9764	2.3635	1.8317	-.2250	1.7856	1.7831	-.0014

Surface interior path 2

1	81.8628	79.1587	1.7989	1.6411	-.0877	1.6967	1.8136	.0689
2	71.7171	69.0311	1.7929	1.7123	-.0449	1.7374	1.6840	-.0307
3	61.6228	59.0156	1.7340			1.8009	1.8821	.0451
4	51.8021	49.0813	1.8095	1.6843	-.0692	1.7907	1.9456	.0865
5	41.6453	38.9467	1.7947	1.6538	-.0785	1.8821	1.8821	.0
6	31.4454	28.8843	1.7033	1.6386	-.0380	1.7958	1.8085	.0071
7	21.5661	18.8720	1.7918	1.7275	-.0358	1.8110	1.7856	-.0140
8	11.5985	8.8110	1.8537	1.8724	.0101	1.8161	1.8034	-.0070

Surface exterior path 1

1	81.4587	78.8601	1.7740	1.6360	-.0778	1.7678	1.6586	-.0618
2	71.5685	69.0352	1.7295	1.5852	-.0834	1.7069	1.7704	.0372
3	61.5173	58.9631	1.7437	1.6113	-.0759	1.7221	1.7755	.0310
4	51.6216	49.0160	1.7788	1.5344	-.1374	1.7043	1.8491	.0849
5	41.6092	38.9703	1.8014	1.5928	-.1158	1.6942	1.8186	.0735
6	31.5288	29.0135	1.7170	1.5878	-.0753	1.7323	1.8136	.0469
7	21.6344	19.0761	1.7463	1.6462	-.0573	1.6586	1.6713	.0077
8	11.3846	9.0707	1.5795	1.5903	.0069	1.5748	1.6535	.0500
9	1.0778	-1.1069	1.4914	1.4836	-.0052	1.4884	1.7374	.1672

Surface exterior path 2

1	81.2987	78.6532	1.8068	1.7326	-.0411	1.8034	1.7348	-.0380
2	71.3241	68.7297	1.7779	1.4404	-.1898	1.7704	1.7120	-.0330
3	61.3214	58.6881	1.7981	1.6294	-.0938	1.8110	1.9177	.0589
4	51.3382	48.6133	1.8627	1.6742	-.1012	1.8288	1.9126	.0458
5	41.3939	38.6509	1.8727	1.7047	-.0897	1.8313	1.7374	-.0513
6	31.2493	28.5969	1.8107	1.6183	-.1063	1.7297	1.6129	-.0675
7	21.3328	18.7650	1.7529	1.5344	-.1246	1.6967	1.6815	-.0090
8	11.2387	8.7346	1.7094	1.6843	-.0146	1.7526	1.6840	-.0391

Test number: B-79-tA

Shell mass: 143.5 g

Material: tantalum

Sabot mass: 4630 g

Wall thickness: 0.48 mm

Impact velocity: 28 m/s

R/t: 79

Shell condition after test: leaktight

Impact plate: steel, 16 rms finish

Surface interior path 1

Dot	ϕ_1	ϕ_2	Initial diameter (y_i), mm	Final diameter (y_f), mm	$\frac{y_f - y_i}{y_i}$	Initial diameter (x_i), mm	Final diameter (x_f), mm	$\frac{x_f - x_i}{x_i}$
1	82.0226	79.5073	1.6711	1.6259	-.0271	1.6815	1.7120	.0181
2	72.1102	69.4560	1.7701	1.7529	-.0097	1.7424	1.7297	-.0073
3	61.9561	59.2353	1.8057	1.8648	.0327	1.7678	1.7602	-.0043
4	51.9410	49.4021	1.6875			1.6408		
5	42.0050	39.3759	1.7475			1.7831		
6	31.9165	29.3149	1.7317	2.0427	.1796	1.7094	2.0168	.1798
7	22.9691	19.3720	2.3823	1.7301	-.2738	1.6866	1.7170	.0181
8	11.8360	9.2846	1.6934	1.7275	.0202	1.6612	1.6713	.0061
9	2.0750	-.7861	1.8997	2.0020	.0539	1.8593	1.9228	.0342

Surface interior path 2

1	81.7198	79.1795	1.6919	1.6920	.0000	1.6916	1.6815	-.0060
2	71.7282	69.1352	1.7077	1.6030	-.0613	1.6688	1.6256	-.0259
3	61.5270	59.1242	1.5941	1.5649	-.0183	1.6866	1.5951	-.0542
4	51.6910	49.1646	1.6790	1.7250	.0274	1.7120	1.7145	.0015
5	41.4939	38.9314	1.7032	1.6970	-.0036	1.6459	1.6637	.0108
6	31.3982	28.8482	1.6974	1.9970	.1765	1.7424	1.8999	.0904
7	21.1150	18.9053	1.4529	1.7326	.1925	1.6993	1.7145	.0090
8	11.5304	8.9971	1.6818	1.7199	.0227	1.6662	1.6916	.0152

Surface exterior path 1

1	81.6726	79.1159	1.7189	1.7707	.0302	1.6815	1.6637	-.0106
2	71.5977	69.1922	1.6229	1.6640	.0253	1.5723	1.6231	.0323
3	61.5242	58.8354	1.8049	1.9182	.0627	1.7145	1.7424	.0163
4	51.4243	48.8938	1.7015	1.6615	-.0235	1.7069	1.7120	.0030
5	41.4259	38.9051	1.6949	1.8546	.0942	1.6739	1.5088	-.0986
6	31.3107	28.7732	1.7082	1.6843	-.0140	1.6688	1.5062	-.0974
7	21.3025	18.7386	1.7157	1.6996	-.0094	1.7196	1.6662	-.0310
8	11.2001	8.6707	1.6978	1.6310	-.0394	1.6916	1.6307	-.0360
9	1.1305	-1.3416	1.6600	1.6183	-.0251	1.6993	1.6840	-.0090

Surface exterior path 2

1	82.0767	79.3712	1.8226	1.7428	-.0438	1.6764	1.7145	.0227
2	71.9268	69.3630	1.7079	1.8063	.0576	1.7272	1.6891	-.0221
3	61.9006	59.2756	1.7620	1.6742	-.0498	1.7272	1.7247	-.0015
4	51.7666	49.2202	1.7121	1.5751	-.0800	1.7348	1.7196	-.0088
5	41.7009	39.1301	1.7286	1.7631	.0199	1.7094	1.6888	-.0238
6	31.5357	29.0552	1.6701	1.5928	-.0462	1.7247	1.5316	-.1119
7	21.5969	18.9150	1.7866	1.7047	-.0459	1.7882	1.7348	-.0298
8	11.2957	8.8513	1.6412	1.6259	-.0093	1.7501	1.7297	-.0116

Test number: C-79-tA

Material: tantalum

Wall thickness: 0.48 mm

R/t: 79

Shell mass: 153.2 g

Sabot mass: 4630 g

Impact velocity: 43 m/s

Shell condition after test: leaktight

Impact plate: steel, 16 rms finish

Surface interior path 1

Dot	ϕ_1	ϕ_2	Initial diameter (y_i), mm	Final diameter (y_f), mm	$\frac{y_f - y_i}{y_i}$	Initial diameter (x_i), mm	Final diameter (x_f), mm	$\frac{x_f - x_i}{x_i}$
1	80.9184	78.4309	1.6600	1.6920	.0192	1.6688	1.6612	-.0046
2	70.9769	68.4324	1.7002	1.7097	.0056	1.6713	1.6586	-.0076
3	60.8450	58.4423	1.6026	1.6055	.0018	1.6485	1.6459	-.0015
4	50.9688	48.4452	1.6854	1.6057	-.0473	1.7170	1.5951	-.0710
5	41.0147	38.4481	1.7111	1.7555	.0260	1.7374	1.6205	-.0673
6	30.9982	28.4274	1.7162	1.8190	.0599	1.6942	1.8085	.0675
7	21.1914	18.6261	1.7119	1.7631	.0299	1.7983	1.8059	.0042
8	11.1846	8.7846	1.6023	1.6183	.0100	1.6307	1.5875	-.0265
9	1.7625	-.7903	1.7044	1.6920	-.0073	1.7094	1.6764	-.0193

Surface interior path 2

1	80.2920	77.8601	1.6226	1.6259	.0020	1.7043	1.6078	-.0566
2	70.3699	67.9338	1.5915	1.6996	.0679	1.7399	1.5900	-.0861
3	60.3228	57.9662	1.5719	1.6335	.0392	1.6485	1.5240	-.0755
4	50.6841	48.0299	1.7702	1.6895	-.0456	1.7653	1.6535	-.0633
5	40.5523	38.0759	1.6504			1.6535		
6	30.7315	28.2732	1.6427	1.6691	.0161	1.6967	1.6256	-.0419
7	20.8567	18.4150	1.6314	1.5827	-.0298	1.6535	1.5291	-.0753
8	11.0693	8.6318	1.6267	1.7072	.0495	1.7018	1.6916	-.0060

Surface exterior path 1

1	80.4115	78.0493	1.5965	1.5700	-.0166	1.5113	1.5519	.0269
2	70.5755	68.2213	1.5930	1.6564	.0398	1.5875	1.6332	.0288
3	60.6437	58.2645	1.6069	1.6411	.0213	1.6205	1.6408	.0125
4	50.7424	48.2841	1.6627	1.6804	.0107	1.6840	1.7170	.0196
5	40.7884	38.4481	1.5794	1.6640	.0536	1.7475	1.4961	-.1439
6	30.8190	28.5149	1.5572	1.5268	-.0195	1.4834	1.5519	.0462
7	20.8150	18.3914	1.6371	1.5166	-.0736	1.5900	1.5824	-.0048
8	10.9374	8.5318	1.6257	1.6081	-.0108	1.6637	1.5951	-.0412
9	1.0305	-1.5625	1.7526	1.7911	.0220	1.7653	1.8059	.0230

Surface exterior path 2

1	80.3351	77.9434	1.6129	1.6818	.0427	1.5824	1.5875	.0032
2	70.2866	68.0700	1.4638	1.5954	.0899	1.5469	1.6027	.0361
3	60.4464	58.0701	1.6024	1.6208	.0115	1.5469	1.6231	.0493
4	50.5646	48.1883	1.6052	1.7973	.1197	1.5672	1.6612	.0600
5	40.6953	38.2759	1.6329	1.6665	.0206	1.5900	1.6485	.0367
6	30.6177	28.2288	1.6158	1.7148	.0613	1.5646	1.6205	.0357
7	20.7178	18.2053	1.6988	1.5700	-.0758	1.6180	1.6993	.0502
8	10.7735	8.3582	1.6313	1.6640	.0200	1.6180	1.6688	.0314

Test number: D-79-tA
 Material: tantalum
 Wall thickness: 0.48 mm
 R/t: 79

Shell mass: 157.9 g
 Sabot mass: 4630 g
 Impact velocity: 61 m/s
 Shell condition after test: leaktight
 Impact plate: steel, 16 rms finish

Surface interior path 1

Dot	ϕ_1	ϕ_2	Initial diameter (y_i), mm	Final diameter (y_f), mm	$\frac{y_f - y_i}{y_i}$	Initial diameter (x_i), mm	Final diameter (x_f), mm	$\frac{x_f - x_i}{x_i}$
1	81.6462	79.1826	1.6411	1.6106	-.0185	1.5773	1.5951	.0113
2	71.5588	69.1186	1.6257	1.6487	.0141	1.6027	1.6104	.0048
3	61.3242	58.8770	1.6268	1.4994	-.0783	1.6231	1.6129	-.0063
4	51.3118	48.9452	1.5767			1.6053		
5	41.3522	38.8884	1.6410	1.5090	-.0804	1.6027	1.6027	.0
6	31.0954	28.6996	1.5942	1.5141	-.0503	1.5596	1.7602	.1287
7	21.3053	18.9234	1.5840	1.5293	-.0345	1.5951	1.6104	.0096
8	11.1499	8.7791	1.5739	1.6208	.0298	1.5900	1.5799	-.0064
9	1.7028	-.7917	1.6569	1.6360	-.0126	1.6866	1.5799	-.0633

Surface interior path 2

1	81.5656	78.9865	1.7173	1.5954	-.0710	1.6459	1.5443	-.0617
2	71.4282	69.0602	1.5778	1.5319	-.0291	1.5799	1.6510	.0450
3	61.3214	58.9548	1.5705	1.4789	-.0583	1.6129	1.6027	-.0063
4	51.5396	49.1660	1.5811			1.6434		
5	41.4759	38.6384	1.8894	1.4988	-.2067	2.0066	1.5494	-.2278
6	31.3954	29.7163	1.1151	1.4658	.3145	1.5951	1.5469	-.0303
7	21.4039	18.9650	1.6226	1.6360	.0083	1.6307	1.6434	.0078
8	11.5665	9.7124	1.2312	1.5776	.2813	1.6485	1.5469	-.0616

Surface exterior path 1

1	81.3226	78.9809	1.5808	1.4632	-.0743	1.5672	1.5494	-.0113
2	71.5741	68.9838	1.7479	1.9690	.1265	1.6942	1.7018	.0045
3	61.4589	59.0020	1.6546	1.6730	.0115	1.6231	1.6358	.0078
4	51.3729	49.0216	1.5871	1.4175	-.1069	1.5469	1.5342	-.0082
5	41.3884	38.9759	1.6280	1.4429	-.1137	1.6027	1.5672	-.0222
6	31.3385	28.9899	1.5830	1.5014	-.0516	1.6434	1.6688	.0155
7	21.2233	18.9331	1.5425	1.5014	-.0266	1.6205	1.6535	.0204
8	11.2693	8.9152	1.5829	1.5573	-.0162	1.5926	1.5875	-.0032
9	1.3291	-1.1694	1.6810	1.6005	-.0479	1.6739	1.6586	-.0091

Surface exterior path 2

1	81.4712	79.0601	1.6275	1.6564	.0177	1.5570	1.6764	.0767
2	71.5435	69.0491	1.6833	1.5573	-.0749	1.6078	1.6332	.0158
3	61.4700	59.0659	1.6164	1.5461	-.0435	1.6485	1.5748	-.0447
4	51.4868	49.0424	1.6497	1.4505	-.1207	1.6053	1.3183	-.1788
5	41.6828	38.8884	1.8854	1.5649	-.1700	1.8288	1.8313	.0014
6	31.3302	28.8496	1.6693	1.6055	-.0382	1.6408	1.6129	-.0170
7	21.2761	18.8581	1.6293	1.6208	-.0052	1.6104	1.5799	-.0189
8	11.1610	8.7652	1.6114	1.5115	-.0620	1.5519	1.5469	-.0033

Test number: E-79-tA

Shell mass: 150.8 g

Material: tantalum

Sabot mass: 4625 g

Wall thickness: 0.48 mm

Impact velocity: 76 m/s

R/t: 79

Shell condition after test: leaktight

Impact plate: steel, 16 rms finish

Surface interior path 1

Dot	ϕ_1	ϕ_2	Initial diameter (y_i), mm	Final diameter (y_f), mm	$\frac{y_f - y_i}{y_i}$	Initial diameter (x_i), mm	Final diameter (x_f), mm	$\frac{x_f - x_i}{x_i}$
1	81.9142	79.4156	1.6604	1.6106	-.0300	1.7094	1.7348	.0149
2	71.4074	68.8963	1.6688	1.6335	-.0211	1.6866	1.6485	-.0226
3	61.2270	58.8854	1.5560			1.5621		
4	51.4077	48.9063	1.6639	1.5446	-.0717	1.6510	1.8009	.0908
5	41.4600	38.9301	1.6873	1.6233	-.0379	1.6739	1.7196	.0273
6	31.4413	28.8330	1.7384	1.5928	-.0837	1.6993	1.6789	-.0120
7	21.6206	18.9734	1.7604	1.7301	-.0172	1.7069	1.7577	.0298
8	11.6162	8.9929	1.7407	1.7479	.0041	1.7170	1.5977	-.0695
9	1.9653	-.8847	1.8911	1.8343	-.0300	1.7653	1.8186	.0302

Surface interior path 2

1	81.4323	78.8893	1.6933	1.6742	-.0113	1.6993	1.7094	.0060
2	71.3713	68.6797	1.7885	1.7730	-.0087	1.7755	1.7526	-.0129
3	61.3409	58.6476	1.7900			1.7755		
4	51.4882	48.7658	1.8114	1.6386	-.0954	1.7297	1.8263	.0558
5	41.3439	38.7106	1.7562	1.4734	-.1610	1.6383	1.7526	.0698
6	31.3913	28.7496	1.7596	1.5115	-.1410	1.6942	1.6358	-.0345
7	21.4067	18.7831	1.7441	1.6360	-.0619	1.7501	1.8110	.0348
8	11.5068	8.7832	1.8072	1.7987	-.0047	1.7602	1.7399	-.0115

Surface exterior path 1

1	80.7820	78.2545	1.7011	1.6589	-.0248	1.6967	1.7628	.0389
2	70.8783	68.3102	1.7284	1.6310	-.0564	1.8085	1.6612	-.0815
3	60.8700	58.4256	1.6451			1.8364	1.6561	-.0982
4	50.8688	48.4174	1.6518	1.5623	-.0541	1.7805	1.7729	-.0043
5	40.9842	38.4606	1.7063	1.5090	-.1156	1.7348	1.6942	-.0234
6	30.8649	28.4580	1.6249	1.4480	-.1088	1.7145	1.6535	-.0356
7	20.9206	18.4739	1.6472	1.4455	-.1225	1.5519	1.5037	-.0311
8	10.0013	8.4221		1.6259		1.7196	1.7170	-.0015
9	.9153	-.7014		1.7123		1.7043	1.7399	.0209

Surface exterior path 2

1	81.2573	78.7726	1.6759	1.6691	-.0041	1.6332	1.7043	.0435
2	71.2963	68.6505	1.7806	1.2871	-.2772	1.6459	1.6916	.0278
3	61.1937	58.6298	1.7257			1.7170		
4	51.1966	48.5563	1.7814	1.6106	-.0959	1.6764	1.7628	.0515
5	41.2661	38.8856	1.6104	1.4658	-.0898	1.7094	1.6916	-.0104
6	31.2427	28.6691	1.7359	1.4658	-.1556	1.6866	1.6866	.0
7	21.1497	18.6539	1.6805	1.4582	-.1323	1.6612	1.6231	-.0229
8	11.4582	8.6221	1.9051	1.6157	-.1519	1.7475	1.7323	-.0087

Test number: F-79-tA

Material: Tantalum

Wall thickness: 0.48 mm

R/t: 79

Shell mass: 157.7 g

Sabot mass: 4642 g

Impact velocity: 116 m/s

Shell condition after test: leaktight

Impact plate: steel, 16 rms finish

Surface interior path 1

Dot	ϕ_1	ϕ_2	Initial diameter (y_i), mm	Final diameter (y_f), mm	$\frac{y_f - y_i}{y_i}$	Initial diameter (x_i), mm	Final diameter (x_f), mm	$\frac{x_f - x_i}{x_i}$
1	81.9767	79.3962	1.7163	1.4393	-.1614	1.6662	1.7424	.0457
2	71.9005	69.4185	1.6855			1.5850		
3	61.9214	59.3506	1.7108			1.6307		
4	51.8952	49.3258	1.7075	1.4378	-.1579	1.7212	1.7526	.0147
5	41.9175	39.3425	1.7135	1.4658	-.1446	1.6188	1.6205	-.0289
6	31.7885	29.2093	1.7166	1.5700	-.0854	1.6662	1.6866	.0122
7	21.8567	19.1081	1.8254	1.8190	-.0035	1.8136	1.7958	-.0098
8	11.8040	9.1527	1.7607	1.7962	.0202	1.6942	1.7247	.0180
9	1.9097	-.7417	1.7615	1.6996	-.0352	1.6662	1.7221	.0335

Surface interior path 2

1	81.8351	79.3240	1.6699	1.2534	-.2494	1.6307	1.7069	.0467
2	71.6935	69.2255	1.6394			1.5799		
3	61.6020	59.0756	1.6839			1.6408		
4	51.8118	49.2813	1.6815	1.3082	-.2220	1.6104	1.7323	.0757
5	41.6550	39.0273	1.7520	1.7072	-.0256	1.6434	1.7450	.0618
6	31.4940	29.1205	1.5771			1.6281		
7	21.6150	19.1484	1.6381	1.6284	-.0059	1.5926	1.5951	.0016
8	11.6651	9.1263	1.6863			1.6358		

Surface exterior path 1

1	81.5753	79.2031	1.5990	1.6628	.0399	1.5545	1.7348	.1160
2	71.5727	69.1616	1.6595			1.5596		
3	61.5145	59.0451	1.6652			1.6205		
4	51.3271	48.8896	1.6415	1.5166	-.0761	1.6027	1.7170	.0713
5	41.4620	38.9606	1.6868	1.5471	-.0828	1.6510	1.7297	.0477
6	31.2885	28.7024	1.7437	1.5776	-.0953	1.7424	1.7094	-.0190
7	21.1747	18.5109	1.7922	1.7377	-.0304	1.8186	1.8009	-.0098
8	11.1026	8.6138	1.6743	1.7097	.0212	1.6434	1.6916	.0294
9	.9514	-1.3861	1.5732	1.5700	-.0021	1.5596	1.6739	.0733

Surface exterior path 2

1	81.5128	78.8754	1.7776			1.7323	1.7400	
2	71.4616	68.9158	1.7137			1.6586		
3	61.4242	58.8520	1.7372			1.6993		
4	51.3216	48.8355	1.6741	1.5903	-.0501	1.6510	1.7424	.0554
5	41.3481	38.8912	1.6603	1.5903	-.0422	1.7475	1.7145	-.0189
6	31.2718	28.6788	1.7458	1.5928	-.0876	1.6688	1.7475	.0472
7	21.1456	18.6206	1.6986	1.6233	-.0443	1.6840	1.6561	-.0166
8	11.0707	8.6124	1.6540	1.6132	-.0247	1.6180	1.6561	.0235

APPENDIX C

BACKGROUND INFORMATION

Preparation of Test Specimens

Sheets of tantalum and 304 stainless steel are available on site. The first step in fabricating shells from these materials was to generate hemi-shells by a forming operation during which flat sheets are pressed over mandrels. The shells were then annealed, machined, trimmed, and instrumented. In this case instrumentation consisted of etching a dot pattern upon the interior and exterior surfaces of the front or impacting hemi-shell. The next section elaborates upon this subject. The inner and outer radius of each shell as well as the size and location of each dot were then measured and recorded. These measurements are believed accurate to the nearest mil. The remaining operations consisted of welding the hemi-shells by electron beam and checking them for tightness by a helium-leak test. They were then ready to be tested.

Instrumentation

Computer calculations modeling shell-flyer plate impact indicated that, at relatively high impact velocities, surface strain varied from a few percent at the impact point, to a maximum exceeding 30% at 60°-70° from the impact axis, to a few percent at 90° from the impact axis. Figure C-1 illustrates the shell reference system.

Active and passive strain-measuring techniques are available. Active instrumentation in the form of electrical-resistance strain gages can be used in areas where surface strain is less than 10%. In the present case, surface strains in the region of interest greatly exceed the level; therefore, a passive measuring technique was used on all shells.

Passive instrumentation consisted of electrolytically etching a pattern of circular dots on the interior and exterior shell surfaces. These dots were 1.5-2.0 mm in diameter and placed every 10° from impact axis (pole) to equator. Two such rows were etched 90° apart (see Figs. C-2 and C-3). For each dot, we sought a durable circular spot with sharp edges; however, to avoid generating a stress concentration, the dot was not etched more than 0.025 mm deep. Figure C-4 is a close-up view of the dots.

Fig. C-1. Shell reference system, showing region of maximum strain.

Fig. C-2. Dot pattern etched on shell interior.

Fig. C-3. Dot pattern etched on shell exterior.

Fig. C-4. Close-up view of etched dot pattern.

Sabot Design

The flyerplate-sabot was designed to be rigid and infinitely massive relative to the shell. Initially an alumina flyer plate (Young's modulus: 0.345 TPa) was used as a reasonable approximation to a rigid plate. After a few impact tests, however, we found that the fracturing of the alumina plate during impact abraded the shell surface and obscured the dot pattern. Therefore, all subsequent tests used a 13-mm-thick steel impact plate with a 16-rms finish. This minimized the abrasion problem.

A sabot impact plate, ballasted to make it at least twenty times more massive than the shell, approximates an infinitely massive impact plate. With a mass ratio of twenty, the energy available for crushing the shell is within 5% of what would be available with an infinite mass ratio for a given shell mass and impact velocity. This approximation permitted correlation between physically realistic tests and computer-code modeling and showed that, for a given velocity, there is an upper limit to the energy available for crushing a shell. The following calculation shows this limit:

Let M = Mass of shell

K = Ratio of mass of sabot/mass of shell

KM = Mass of sabot

V_1 = Initial velocity

V_2 = Final velocity.

During an inelastic collision, conservation of momentum holds:

$$KM V_1 = (KM + M)V_2.$$

Solving for V_2 ,

$$V_2 = \frac{KM V_1}{M(K + 1)}.$$

Kinetic energy before impact can be expressed as:

$$KE_1 = \frac{1}{2} (KM) V_1^2$$

and kinetic energy after impact as:

$$KE_2 = \frac{1}{2} (KM + M) V_2^2 = \frac{1}{2} \frac{K^2 M V_1^2}{(K + 1)}.$$

Assume all kinetic energy lost is available for crushing the shell.

Available crushing energy is $KE_1 - KE_2 = \frac{1}{2} MV_1^2 \left(\frac{K}{K+1} \right)$.

If $K = 1$, available crushing energy, $KE_1 - KE_2 = 0.5 \left(\frac{1}{2} MV_1^2 \right)$.

If $K = 20$, available crushing energy, $KE_1 - KE_2 = 0.95 \left(\frac{1}{2} MV_1^2 \right)$.

If $K \rightarrow \infty$, available crushing energy, $KE_1 - KE_2 \rightarrow 1.0 \left(\frac{1}{2} MV_1^2 \right)$.

For $K = 20$, the available energy for crushing the shell is 95% of the energy available for $K = \infty$; therefore, $K = 20$ is a good approximation to an infinite mass ratio.

The sabot itself is a 200-mm-long tube of G-10 fiberglass with the impact plate mounted in the rear just ahead of the steel end plate (Fig. C-5). Any necessary ballast was added to this endplate. To minimize shell deformation beyond that caused by impact with the flyer plate, we modified the sabot by deeply recessing the impact plate within it, as shown in Fig. C-5. The recessed impact plate helped form a cavity in the sabot that the shell occupied during deceleration. Without the cavity, the shell would deform by being sandwiched between the impact plate and the recovery container. After impact between the shell and sabot, the two undergo about a meter of free flight before decelerating by impacting an open container filled with rags. In preliminary tests, the rags permitted a gentle enough recovery that a few recovered sabots were suitable for reuse.

Experimental Procedure

For the impact tests, we used the 100-mm gas gun in Building 341. The gun consists of a breech, a 30-mm barrel, a test section, and a catch tank. A variety of breeches can be fitted to the gun, depending upon experiment requirements. For these tests, a breech known as the Wilson valve was used. After the ballasted sabot is loaded into the breech, the gun is evacuated. A vacuum of about 100 microns is sought. The gun is fired by discharging a pre-selected level of air pressure into the breech. As an example, a pressure of 0.62 MPa was needed to accelerate a 3.0-3.5-Kg sabot to 0.12 mm/ μ s. Pins located very near the gun muzzle measured actual impact velocity.

Fig. C-5. Diagram of sabot and flyer plate.

The flyer plate impacted a stationary shell mounted in an adjustable, break-away fixture placed near the gun muzzle (Figs. C-6 and C-7). The patterns on a shell were oriented with respect to the pole and equator. We then aligned the shell so that it would impact on the pole (Fig. C-8). Alignment consisted of determining which point on the shell was touched first, then rotating and/or translating the shell so that the touch point was at the pole and was roughly in the center of the impact plate. If the shell had impacted at a point other than the pole, it would have been necessary to determine this point and reference strain measurements to it, a difficult operation. In order to maintain alignment, the impact plate should hit the shell before any other parts contact. To ensure that this was the first contact, the shell was mounted in the forward end of a cantilevered support tube as shown in Fig. C-8. This tube is part of the break-away fixture.

Two x-ray cameras located in the test section served two useful purposes: they functioned as a second source of velocity verification, and they provided a photograph of a deformed shell before it decelerated. The upstream camera photographed the shell and impact plate at the time of initial contact. At a velocity of 120 m/s, about 800 μ s are required for the shell and sabot to travel 100 mm downstream to the location of the second camera. Computer code calculations indicate the shell attains its final deformed shape in 300-700 μ s; therefore, the downstream camera, triggered later and separately from the first, revealed the final shape of a shell before it began decelerating in the rags.

Fig. C-6. Relationship of sabot to shell and mounting fixture.

Fig. C-7. Close-up view of mounting fixture.

Fig. C-8. Orientation of dot pattern to shell alignment.

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